VOLUME 10 • NUMBER 5 • MAY, 1939

Metals and Alloys

Published Monthly by Reinhold Publishing Corporation, East Stroudsburg, Pa., U.S.A. Ralph Reinhold, President and Treasurer; H. Burton Lowe, Vice President and Secretary; Philip H. Hubbard, Vice President; Francis M. Turner, Vice President. Executive and Editorial Offices, 330 West 42nd Street, New York. Price 25 cents a copy. Annual Subscription: U. S., Possessions and Canada, $2.00. All Other Countries, $3.00. (Remit by New York Draft). Entered as second class matter June 12, 1934, at the Post Office at East Stroudsburg, Pa., under the Act of March 3, 1879.

Articles

Metallurgical Abstracts

To the Man who says,

HERE'S PROOF!

"We make cold pressed nuts. With the steel formerly used, we processed from 4000-8000 lbs. of nuts per day. Last month, using U·S·S Controlled Steel, our records show we processed from 8000-11,000 lbs. per day, about the maximum that can be obtained on our machines. Have about doubled our output. Our production jumped 700% between tool settings.

"On one set of dies we formerly processed 10 to 20 tons of material. We now process 140 tons. 400 to 3000 nuts was the best we could get with one punch—now we get 20,000. Do you wonder we're enthusiastic about U·S·S Controlled Steels?"

MORE PROOF!

"We make connecting rods, cams, front axles and other automotive forgings. Ease of forging, well-filled sections, and uniformity in heat treatment are advantages that U·S·S Controlled Steels have shown in our plant. Freedom from trimmer cracks and quench cracks, together with marked toughness after heat treating, is also imparted by these steels. So is definite control of hardness from center to outside of each product. By using U·S·S Controlled Steels and our special agitating equipment, we've minimized the scale effect on hardenability, and in addition have materially reduced cleaning costs through this freedom from scale."

STILL MORE PROOF!

"We make screw machine parts. We supply an infinite variety of specialty products to fabricating shops, whose requirements are both specific and different. Our cold drawn steel requirements are rigid from the standpoint of machinability, finish, and uniformity of physical characteristics. When our products are subjected to heat treatment, they must have uniform properties, which can only be secured by careful control in the manufacture of the steel. So, in buying cold drawn bars, we specify U·S·S Controlled Steels—both Open Hearth and Bessemer—to provide the uniformity so essential in keeping our customers satisfied."

UNITED

A Symposium on Temperature

The metallurgical engineer will view with approval the plans of the American Institute of Physics to hold a Symposium on Temperature and its Measurement in Science and Industry. Appreciation of the fact that physics is the basis of engineering and that the teachers of physics must be forced to remember that this basis ever needs broadening is likely to be increased by such a conference.

Industry's chief quarrel with physics, as it has been taught in the last decade, is that it tends to overemphasize the quantum point of view and high-brow speculations on atomic structure to the exclusion of more tangible problems. The tendency has been, in graduate work, to train men to be professors of high-brow physics that they may train other men to be, in their turn, professors of a similar type. Inbreeding, over-production, and gross neglect of everyday engineering physics have resulted. It is a pleasure to note a movement within the ranks of the physicists themselves to remedy this situation.

A physicist with his feet on the ground is a most useful animal. One with his head in the clouds may be potentially useful in respect to pure science, but the proportion of physicists of sufficient stature to have both extremities in both places is very small. We'd rather see all physicists trained so thoroughly in truly engineering physics that all will have their feet on the ground and only those inherently of sufficient stature get their heads in the clouds. Only heads of men of large stature can look into the future anyhow. Many who are incompetent in respect to forward-looking pure physics would be competent to apply known physics to engineering and to broaden the base of engineering by research in low-brow physics.

In the last decade or so, many men have been permanently spoiled by their graduate work in physics of a type for which they are not fitted, but which type they nevertheless stick to, or remain unemployed because of lack of positions in work requiring that brand of physics. They have not had adequate grounding in the type of physics that industry needs and could profitably create jobs in.

If engineers could be induced to take graduate work in engineering physics after their regular course in engineering, or if graduates in general physics did their own graduate work in engineering rather than in high-brow physics, the situation might be improved.

At any rate, the more discussions that are held on the down-to-earth type of physics, the better the chance for much needed improvement in a situation that vitally concerns the future of metallurgical engineering.—H.W.G.

While the Iron is Hot

We note that M. I. T. is to inaugurate "short courses" on powder metallurgy. Tech has previously handled in its summer sessions such topics as fatigue, creep, spectroscopic analysis, etc. In some of these cases the staff, with perhaps a guest speaker or two, prepares the way through a series of lectures, so that the graduate students and the men from industry who attend secure a connected background, and in a final session outside experts sum up the topic as it affects industry.

This is quite different from the prevalent idea that a university teaches only information that is already old, if not out of date, in industry, even though it is a proper foundation to superpose the later ideas and facts upon. These M.I.T. topics are hot, information on them is still in the making and cannot be set forth with the usual academic finality. The sum total of known truth brought out in such attempts to assemble it is not always very great, and an immature mind might be bewildered rather than brought to clear thinking, even by the best possible assembly. But such conferences are designed for the mature and for those who are vitally interested; they aren't summer courses for schoolmarms.

The effort to deal promptly with matters of importance to engineering before the fundamentals are as thoroughly established as a teacher might like from a pedagogical point of view is certainly praiseworthy. It evidences a point of view and a feeling of responsibility to industry that well become a school of technology. That special attention is thus being given to live topics in metallurgical engineering is particularly pleasing.—H. W. G.

These Unique Structures—the Perisphere and Trylon—dominate the Fair. The underneath portion of the ramp which leads to the perisphere and is supported by the pillars, is lined with stainless steel sheets. The reflection of the pillars is visible in the highly polished sheets.

Metals and Alloys at the New York World's Fair

One of Two 9-Ft. American Eagles to be Located on Top of 150-Ft. Flag Poles at either End of the Lagoon of Nations. This statue is fabricated of welded sheet steel covered with gold leaf—pointed to by the artist as more closely related to modern steel archictectural construction than the traditional work in plaster and stone.

At the New York World's Fair, Inc., 1939, Flushing Meadow Park, N. Y., — which opened its gates April 30—metals and alloys naturally play a very important part. The theme of the Fair is "The World of Tomorrow," and the manner in which metals are being used indicates to some extent a few of their future applications. Among these are murals, statues, fountains, weather vanes, flag poles, decorative doors and panels, and so on. There is a strong tendency towards the construction of murals of metals and alloys, and some of these are highly effective and arresting. In the murals, and in other uses, stainless steel, welded steel plates and sheets, nickel-silver, copper, brass, aluminum, chromium plating and others are incorporated. Of course structural steel predominates in most of the buildings and its use in the Trylon and Perisphere is noteworthy.

Outstanding among the murals already installed as the Fair opened are eight murals of "pierced brass" on the outside of the Contemporary Art Building, the theme of which is "Arts of the Western Continent"; a mural of "polished chromium sheet metal" (stainless steel) on the outside north wall of the Business Systems and Insurance Building, entitled "The Great Discoveries of Man"; a metal mural, 14 by 21 ft., —"Hippocrates Banishes Superstition and Introduces the Light of Scientific Method"—on the exterior of the Medical and Public Health—Science and Education Building; and last but not least, a mural of "ferro enamel," the first outdoor mural work in ferro enamel or porcelain enamel on steel. These latter are striking in the color scheme of yellow, orange, blue and plum. In the interior of the U. S. Steel Corp. Building is a large mural of stainless steel, a masterpiece of its kind. There are 105 murals in the Fair, most of them made of other materials than metals. But those of metals and alloys afford a glimpse of the possibilities.

Among the 102 pieces of sculpture on the grounds, one type, constructed of metal, is new and worth special mention. It is of welded steel, the conception of a young artist, Robert Foster. By the same artist is the Statue of Mercury on the Ford Building. It is 25 ft. high and weighs 3 tons and is formed entirely of bent stainless steel sheets, electrically welded.

At the impressive dedication of the General Motors Building, Wednesday evening, April 19, at which many leading industrialists were present, a preview of "Highways and Horizons" was given. In the spacious room where the dinner was served, copper is prominent as a decorative material. It is also understood that the General Electric Building is sheathed on the outside with copper.

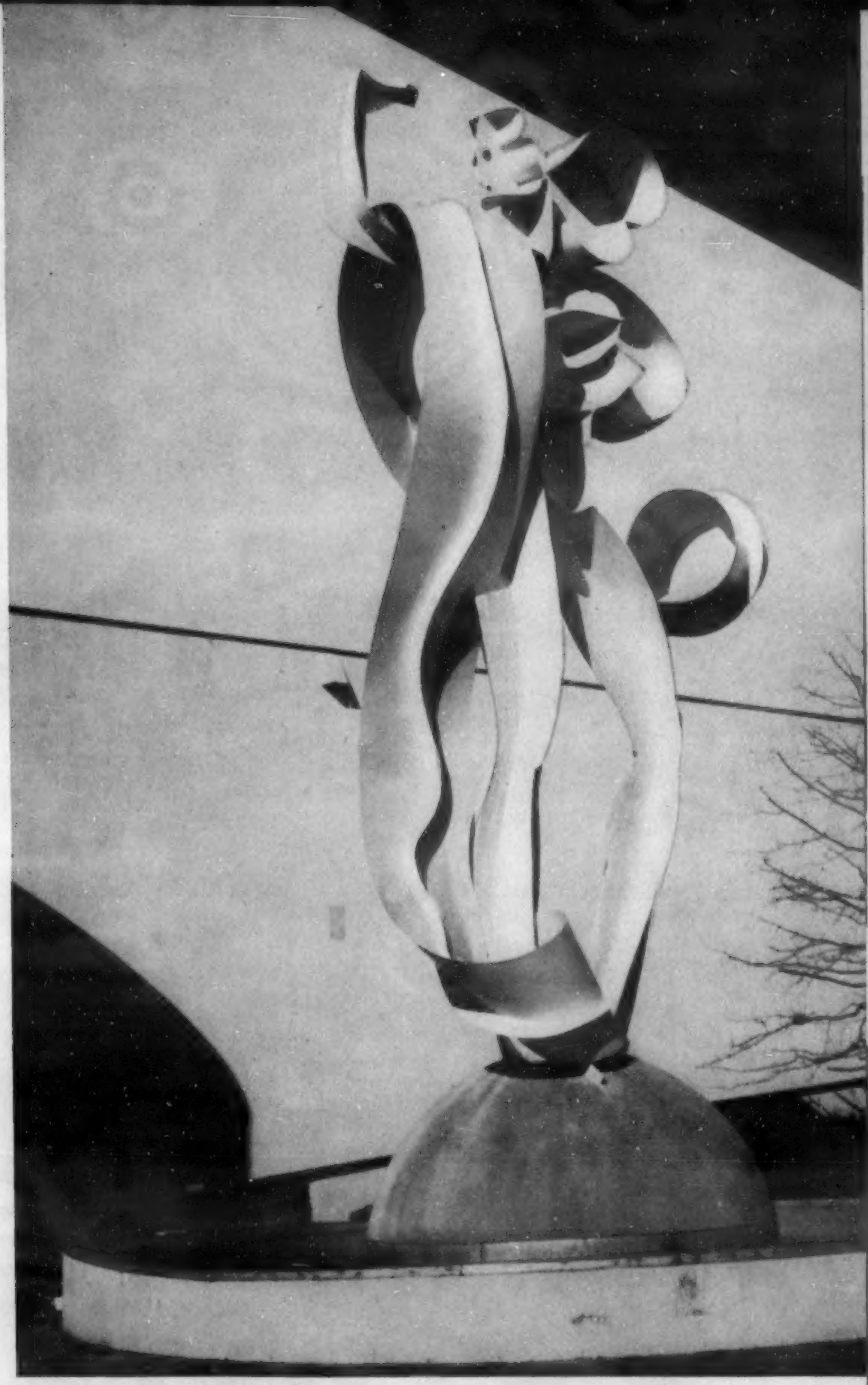
Metals are prominent in the tower of the Polish Building and it is said that the statue on the high tower of the Russian Building is largely metal.

On the accompanying pages we have been able to reproduce a few of the murals, statues and so forth which are available and it is probable that others can be reproduced from time to time.—E. F. C.


COPPER

A Night View of the Metals Building. In this building the displays of the Copper and Brass Industry and of the Bethlehem Steel Co. are features.

General View of the Large Display of the Copper and Brass Industries in the Metals Building. It tells the story of copper—the oldest metal of commerce—from its discovery to the present time. An animated copper atom is a spectacular feature.

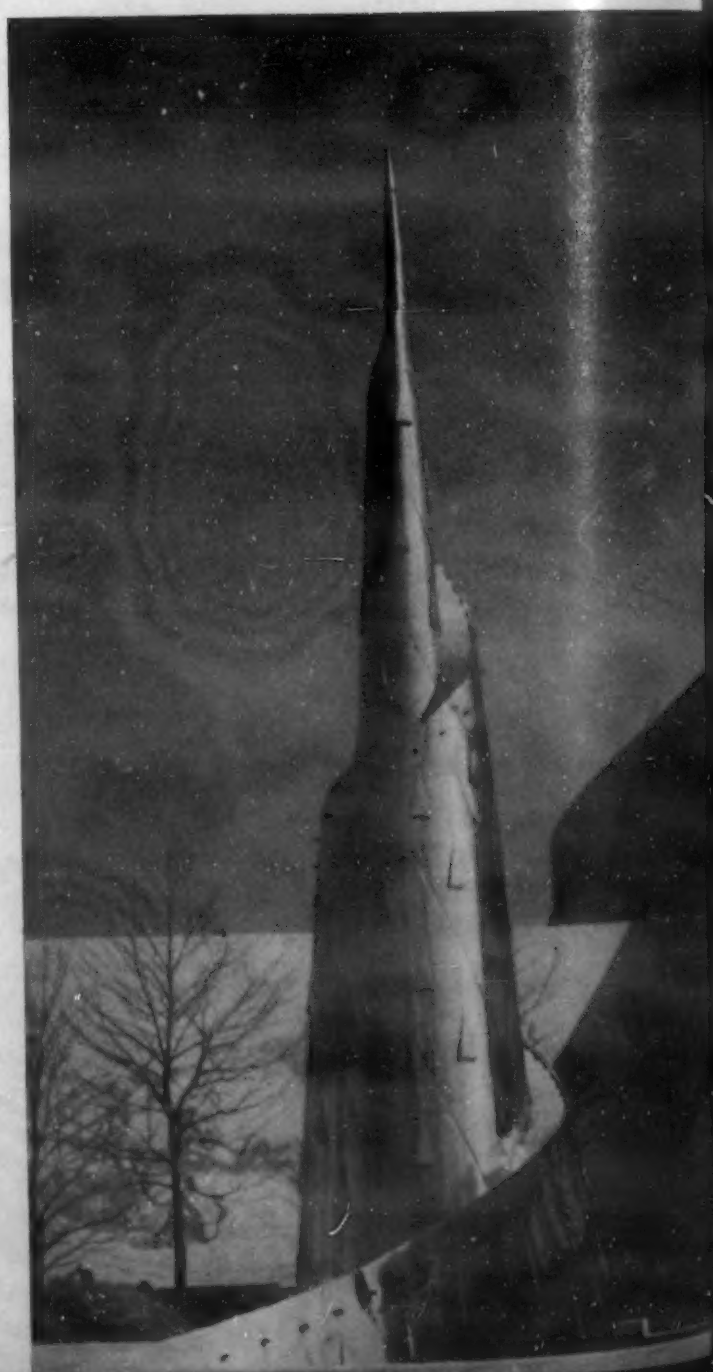


A Welded Steel Statue—"Textiles"—Located at One of the Main Entrances to the Hall of Fashion. It represents a woman with a swatch of cloth on her arm.

Gleaming in Sunlight is The Stainless Steel Building of the United States Steel Corp. The dome, 66 ft. high and 132 ft. in diameter, is covered with 28,000 sq. ft. of stainless steel. Through the main entrance can be seen part of a large mural, made of stainless steel sheets and strip.

A Mural of Ferro Enamel. It is one of five beautiful ones on the exterior of the Home Furnishings Building. The base is a soft steel. During the various firing operations, the plates are heated in an electric furnace at 1700 deg. F. The large mural is 72 ft. long and 27 ft. high.

The "Genius of Progress," One of a Series of Three Murals on the Business Systems and Insurance Building. They are made of polished chromium stainless steel with red and black color against a white wall. The subject of the group of these murals is "The Great Discoveries of Man."



One of the Stainless Steel Fountains on the Grounds. On one side of this court are displays relating to Science and Education and on the other, exhibits dealing with the subjects of Medicine and Public Health. Some of the murals are visible in the background

Above: These Four Large Stainless Steel Umbrellas House the Exhibit of the Edward G. Budd Mfg. Co., Philadelphia. They can shelter about 10,000 persons. The world's largest weather vane, 90 ft. high, has a wind direction indicator 80 ft. long. The mast is of stainless steel.

Parts of a Set of Nickel-Silver Doors at the Main Entrance of the British Pavilion. The weight of each door is 3½ cwt. The material is "Wiggin 20 per cent nickel silver"—an alloy of nickel, copper and zinc. The lions are cast in bronze.

Short-Cycle Annealing of Malleable Iron

So much interest is shown in present-day rapid malleableizing equipment, even by smaller producers that it is timely to give a brief description of the modern processes and to illustrate some of the furnaces and auxiliaries employed.

Ten years ago, standard American malleable production methods consisted generally of placing the charges in scale- or ore-filled pots, covering, heating to around 1600 deg. F. in 30 to 40 hrs., soaking there at 50 to 65 hrs., cooling to about 1200 deg. F. for 80 to 90 hrs., and finally rapidly cooling to 600 deg. F. before discharging. A total time cycle of 200 hrs. was therefore not at all unusual.

Speeding up the malleableizing operation so as to bring it more in line with production advances in other processes had to be accomplished with no important sacrifice of the traditional quality of American malleable—good machinability, elongation around 20%, tensile strength over 50,000 lbs. per sq. in., characteristic shock-resistance, etc. Modern fully-annealed short-cycle malleable is not at all inferior to the conventional product; shortening of the cycle to its present period of 12 to 50 hrs. has been accomplished by raising the annealing (soaking) temperature, by using lower carbon and higher silicon contents to hasten graphitization, and by employing controlled atmospheres instead of oxide-packings, to permit a higher net metal percentage in the furnace charge; the frequent use of continuous equipment has also aided in shortening the cycle.

This all applies to the production of *fully-annealed* malleable, *i.e.* iron whose microstructure is substantially temper carbon in ferrite, with no cementite, pearlite or sorbite evident. The new "pearlitic malleables" are also annealed in extremely short cycles, but their properties—better in some respects, poorer in others—are quite different. This description of two typical short-cycle annealing installations and the accompanying illustrations refer to the fully-annealed product with conventional microstructures. We are indebted to W. F. Ross of the Electric Furnace Co., Salem, Ohio, for the data.

One large Canadian producer has recently installed two identical electrically heated (340-kw.) malleableizing furnaces of the continuous pusher, roller rail conveyor type. Each furnace can handle 833 net lbs. of iron per hr., with a total time cycle of 36 hrs. in the furnace. Fig. 1 shows the charging end of these two units. Two trays, each loaded with an average of 440 lbs. of castings are simultaneously charged into each furnace at 63 or 64 min. intervals. Moving along on the hydraulic pusher-operated roller rail conveyor extending the length of the furnace and cooling chambers, the charge is quickly heated to 1500 deg. F., then slowly heated to 1700 deg. F., allowed to soak at least 10 hrs., then quickly cooled to 1400 deg. F., slowly cooled to 1300 deg. F., and discharged. Fig. 1 shows the application of the return conveyor for empty containers and indicates the position of the "Elfurno" atmosphere generator atop the furnaces. Electric heating was selected for this installation, but under conditions favorable to the use of gas, such equipment as this could readily be designed for gas-fired radiant tube heating.

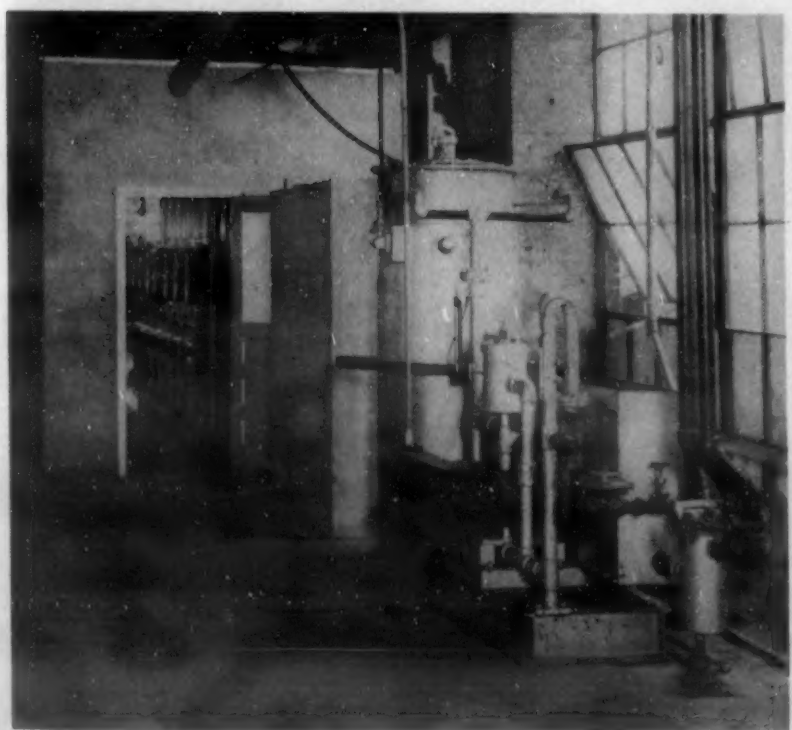
In roller hearth conveying, the movement of the charge is continuous at a uniform rate of speed, rather than by periodic pushes. An electric (860-kw.) malleableizing furnace with this type of conveyor, employing gas-tight lock chambers at both ends to diminish escape of the special atmosphere during charging and discharging, has recently been placed in operation by a producer of automotive castings. The total furnace cycle in this installation is less than 13 hrs. Fig. 2 shows the charging end of the furnace, and illustrates the use of the overrunning drive for charging containers into the lock chamber vestibule. Two trays, each loaded with about 350 net lbs. of castings, are simultaneously charged at 16-18 min. intervals—the equipment is designed to produce as high as 2900 net lbs. of material per hr. In the furnace, the iron (of slightly lower-carbon, higher silicon content than the usual) is quickly heated to 1750 deg. F., allowed to soak 3 hrs., cooled quickly to 1450 deg. F., slowly cooled to 1150 deg. F. and discharged—the entire cycle requiring only 12 hrs., 36 min.

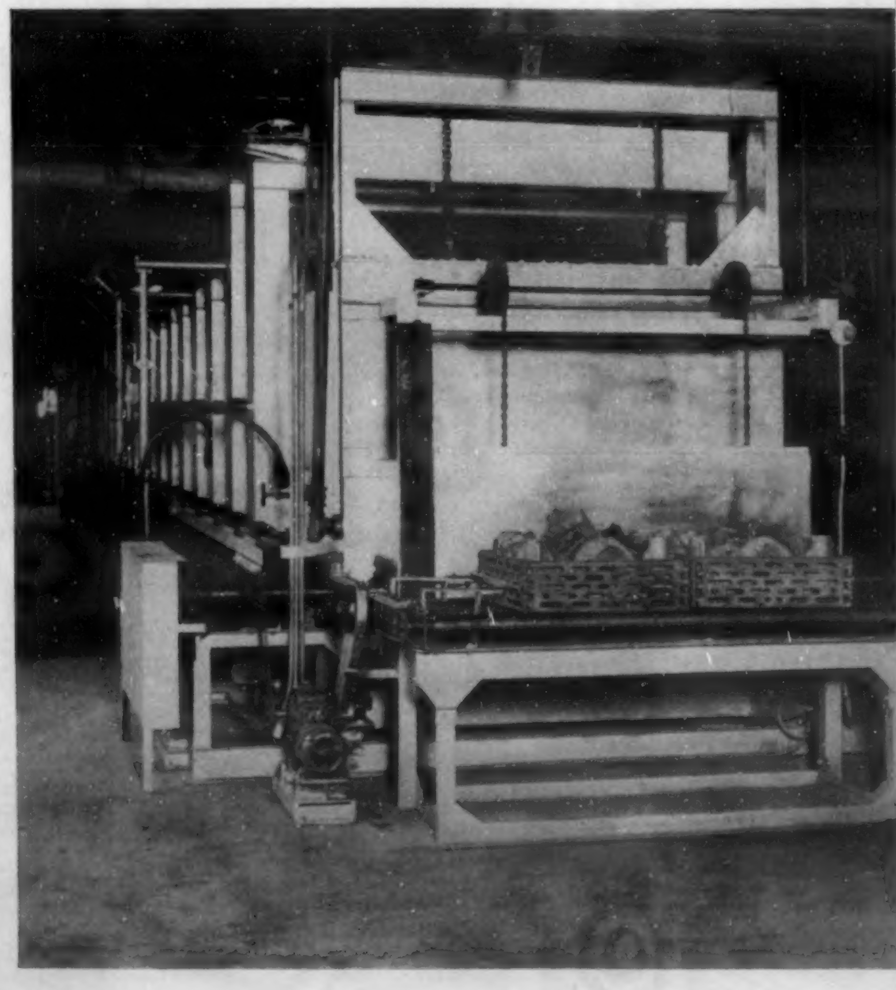
Fig. 3 shows the special atmosphere equipment (on the right), which provides the gas for scale-free malleableizing; in the rear are seen the switching and automatic temperature control equipment so vital to the fool-proof operation of furnaces like this.

Fig. 1. Charging End of Two Continuous Pusher Roller Rail Conveyor Type Electric Malleableizing Furnaces.

Fig. 2. Charging End of Roller Hearth Conveyor Type Electric Malleableizing Furnace.

Fig. 3. Controlled Atmospheric Equipment for Furnace of Fig. 2.





Stainless Forging Metals

by WALDEMAR NAUJOKS

Chief Engineer,
The Steel Improvement & Forge Co.,
Cleveland.

In this article Mr. Naujoks discusses the various ferrous and non-ferrous metals and alloys suitable for manufacture into drop forgings which are non-corrosive. The stainless steels as well as the copper and nickel base alloys are reviewed as to their metallurgical and working properties. Illustrations of forgings made from such metals are included.

—The Editors.

WITHIN A VERY RECENT PERIOD, general consciousness has arisen on the importance of stainless and corrosion resisting metals in commercial and social life. At the present time a large variety of metals are available that may be classed in the so-named group of "stainless metals," or metals that are used for purposes of resisting deterioration to a greater degree than the commercial steels do. The corrosive agents may vary from mild to relatively severe service conditions.

Strictly speaking, none of these metals are truly stainless or resistant to all corrosive conditions. Their ability in this respect depends upon the particular composition, the metallurgical state of the composition, and the conditions of deterioration imposed upon the metal. The general destructive forces imposed upon the metals are chemicals, elevated temperatures, or electrochemical action, with or without high pressures. There are, of course, many conditions where ordinary steels tend to corrode more rapidly than desired and a composition must be used which will successfully resist, for practical purposes, the corrosive action. The variation in conditions may range from mild atmospheric attacks to a severe combination of chemicals, elevated temperatures, and high pressures.

The earliest known of the corrosive resisting forging metals were copper and alloys of copper, and these were used to a wide extent in past centuries. The beginning of the twentieth century found experiments in progress to obtain stainless steels and stronger non-ferrous metals. Stainless steel is a recent innovation commercially, less than 30 years old, and from this beginning, commercial stainless irons and steels, and new important alloys in the non-ferrous field have constantly increased so that today there is a suitable stainless forging metal for practically any purpose. Recognition of the important properties of these corrosion resisting metals is reflected in the extraordinary demand for stainless forgings in products today where such forgings were considered experiments only a few years ago.

General Classification

The stainless metals may be classified as the stainless irons and steels or those metals using iron as a base; and as the non-ferrous metals, where some other base is used and iron enters only as an alloying element or as an impurity.

The basic alloying element in the commercial stainless irons and steels is chromium. When present in proportions of 10 per cent and over, chromium develops its characteristic corrosion resisting properties. Chromium has a high resistance to strong acids and alkalies, to heat, and to electrical conductivity, and a high tensile strength together with resistance to scaling and deformation at elevated temperatures to about 2000 deg. F.

Nickel is next in importance in the stainless irons and steels. In proportions up to about 1.00 or 1.50 percent, it improves the properties of the straight chromium stainless group by increasing the hardness and toughness in the hardenable group, the toughness in the non-hardenable group, and a reduction in tendency towards grain growth in both groups. In percentages from about 7 to 25 percent, nickel with suitable proportions of chromium forms the austenitic chromium-nickel steels, which offer greater resistance to chemical and temperature corrosive conditions than do the straight chromium or the low-nickel chromium irons and steels. The austenitic stainless steels are not hardenable by heat treatment, and to a limited degree by cold working.

Additional alloys such as molybdenum, manganese, tungsten, copper, columbium, titanium, selenium, sulphur, and silicon are used in the austenitic steels to obtain benefits for specific purposes not directly imparted by the chromium and nickel.

The straight chromium, or ferritic chromium stainless irons and steels, ranging in chromium content from about 11 to 18 percent and with a carbon content from about 0.10 to 1.00 percent are produced in several standard commercial compositions.

Ferritic chromium-nickel steels are similar in chromium and carbon composition to the ferritic chromium steels, excepting that a small percentage of nickel (0.50 to 2.00%) has been added to obtain several additional benefits not imparted by chromium alone.

Austenitic chromium-nickel stainless steels are produced in a variety of composition combinations, with the basic and most used composition being 18 percent chromium and 8 percent nickel. This analysis was originally known as KA2 stainless, and is now popularly designated as 18-8 stainless. It has wide popularity both in the regular and in the free machining grades. Some of the better known compositions in addition to the 18-8 stainless are 19-9 (19% Cr-9% Ni), 20-10 (20% Cr-10% Ni), 25-20 (25% Cr-20% Ni) and 8-18 (8% Cr-18% Ni). Additional alloys in suitable proportions are used to obtain special effects not imparted by the chromium and nickel alone.

The non-ferrous corrosion resisting metals are those metals using another element as a base in place of iron. This base is generally copper or nickel.

Copper and its alloys produce many forging metals, the principal ones being the forging brasses and bronzes. Zinc is the primary alloying element for the brasses, and tin, aluminum, and nickel are used to produce a variety of forging bronzes.

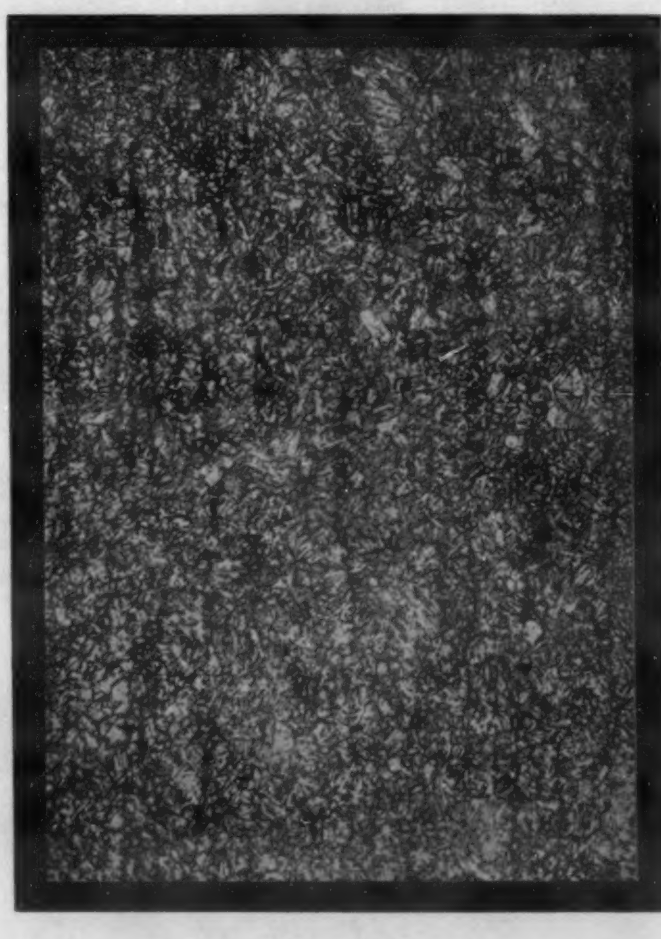
Commercially pure nickel and copper-nickel alloy (monel metal) find extensive use in the stainless metal field. New and recent developments have made available copper-nickel alloys that can be hardened after forging.

Metallurgical Properties

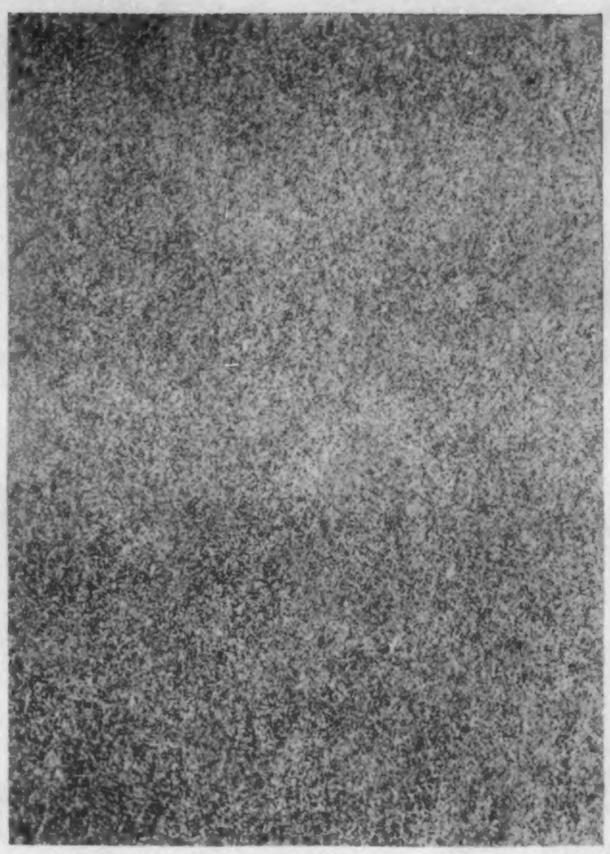
Stainless irons and steels are generally considered in two general groups with relation to physical properties, the hardenable stainless steels and those not hardened by usual heat-treating methods. The ferritic chromium and the ferritic chromium-nickel groups contain compositions that can be hardened and compositions that do not harden by heat treatment. The ability of any composition to harden depends upon the relation of the carbon content to the chromium in the steel. An analysis of 13 percent chromium with a carbon content of 0.10 percent can be hardened to nearly 400 Brinell hardness, but if the chromium content is increased to 17 percent with the same carbon content, the maximum hardness obtainable will be about 200 Brinell. However, if the carbon content is suitably increased with an increase in chromium content, a higher hardness can be obtained in the highr chromium steel. For example, a steel with 13 percent chromium and 0.35 percent carbon can be hardened to about 500 Brinell. If the chromium content is increased to 17 percent and the carbon raised to 0.65 percent, this steel can be hardened to about 575 Brinell. The addition of nickel in

Structure of Type 302 Stainless Steel, Annealed at 1900 deg. F. and Quenched in Water. 100X. (Courtesy: Republic Steel Corp.)

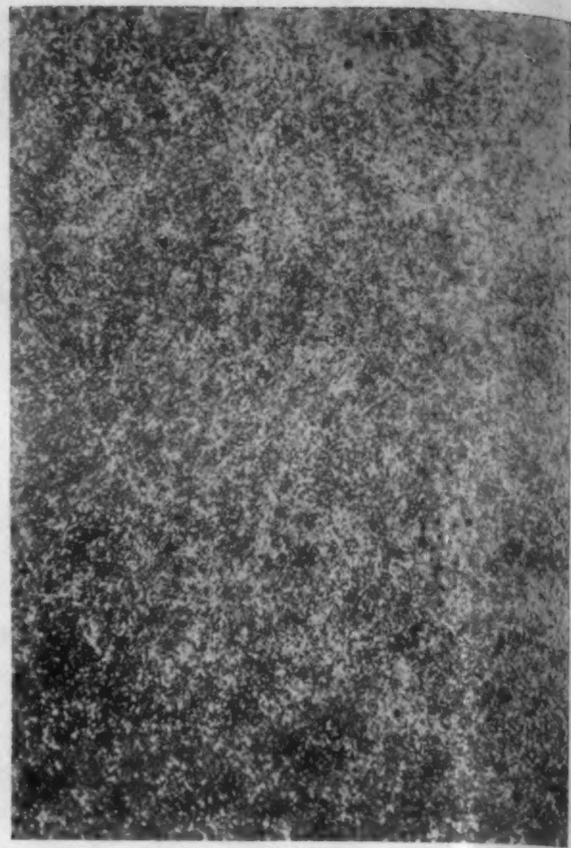
Structure of Type 410 Stainless Steel, Oil Quenched at 1775 deg. F. and Tempered at 800 deg. F. 100X. (Courtesy: Republic Steel Corp.)



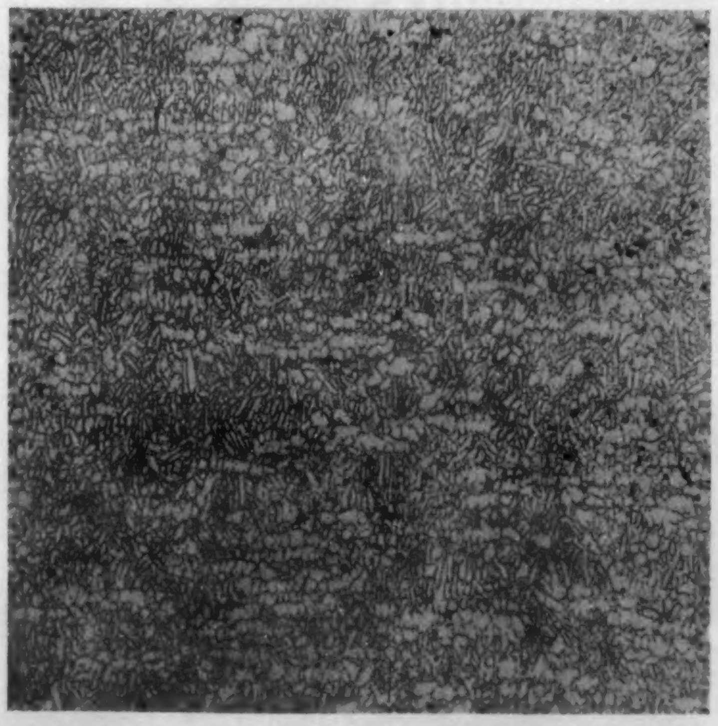
Structure of Type 410 Stainless Steel, Annealed at 1528 deg. F. and Furnace Cooled. 100X. (Courtesy: Republic Steel Corp.)



Structure of Type 440 Stainless Steel, Annealed at 1550 deg. F. and Furnace Cooled. 100X. (Courtesy: Republic Steel Corp.)



Structure of Type 440 Stainless Steel, Oil Quenched at 1850 deg. F. and Tempered at 500 deg. F. 100X. (Courtesy: Republic Steel Corp.)



Structure of Forged Free Turning Brass (Cu 60.5, Zn 37.75, Pb 1.75%) Etchant, H_2O_2-NH_4OH. 75X. (Courtesy: Chase Brass & Copper Co.)

proportions of .50 to 2.00 % tends to intensify the hardness and increases the toughness.

Austenitic stainless steels can not be hardened by the usual heat treatment methods and their particular field of usefulness is in greater resistance to corrosion against chemicals and high temperatures than can be obtained from the ferritic stainless steels.

The heating and heat treatment of all stainless steels is an important factor in developing the valuable properties imparted by their alloys. The high chromium content retards heat penetration into the steel and it is usually necessary to increase the heating period for hot working operations. It is obvious that steel not heated uniformly will present difficulty in hot working, tends to reduce die life, and usually develops a non-uniform, undesirable structure. Modern forging practice in the fabrication of stainless steels requires suitable automatic temperature controls on forging furnaces so that the heating can be adjusted to suit any desired temperature-time heating cycle.

After any forging or hot working operation, all stainless steels should be given a heat treatment in order to obtain the best physical properties and greatest resistance to corrosion. In the high carbon ferritic chromium or ferritic chromium-nickel steels it is mandatory that the steels be hardened in order to obtain the stainless properties.

Generally all stainless steels exhibit their maximum results in resisting corrosion in a polished condition. Many of these steels do not require polishing to resist corrosion, but where such steels are used in the unpolished state, it is desirable to give them a passivating treatment to remove effectively from the surface any iron particles or other foreign matter which may serve as a starting point for electro-chemical attack.

Non-ferrous metals, similar to the stainless steels, may be divided into a hardenable and a non-hardenable group, with respect to obtaining higher physical properties and hardness by heat treatment.

The brasses and some of the bronzes are generally not given a heat treatment. The higher strength bronzes often develop good properties by heat treatment, and nickel or alloys high in nickel such as monel metal are usually given a heat treatment to normalize the structure.

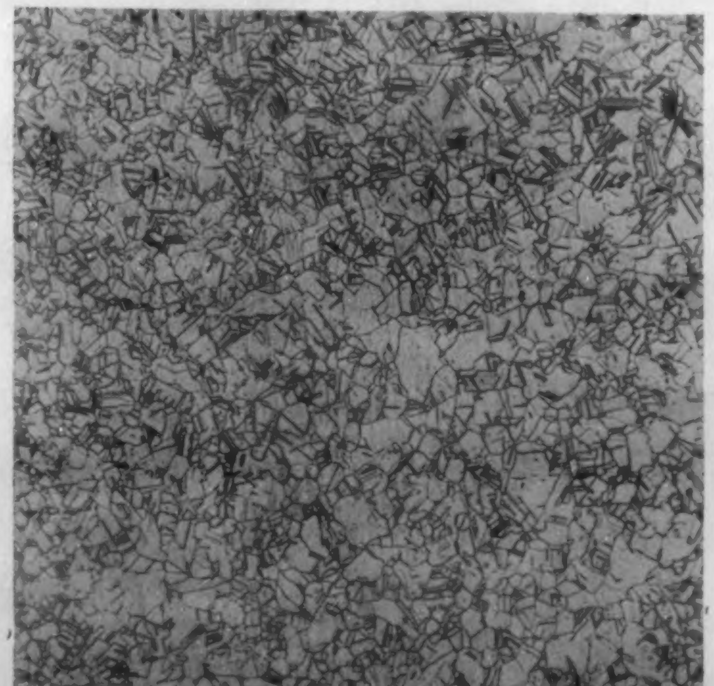
Heating is important in all of the non-ferrous metals. Many of these alloys have a close hot working range, some, through an affinity for sulphur, require a sulphur-free fire, and others require slow careful heating.

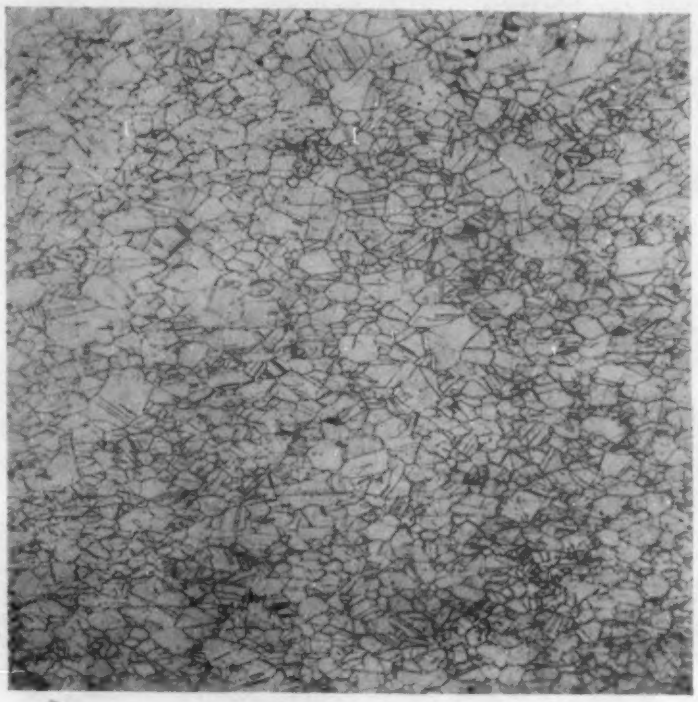
Working Properties

Hot and cold working properties of the stainless metals are of highest importance. The ease or difficulty of cutting, forming, forging, machining, polishing, or otherwise processing the metal determines to a large degree its commercial value. For many corrosion resisting problems, one of several corrosion resisting metals may be used, and since the final cost of the finished part is dependent upon processing costs as well as the first cost of the metal itself, working properties are important.

None of the straight chromium or the chromium-nickel stainless irons and steels are as easily worked as commercial carbon steels. Since chromium has a high resistance to deformation at elevated temperatures, it is evident that steels containing a large percentage of chromium will offer greater resistance to hot and cold working operations than do ordinary commercial carbon steels. The resistance of chromium to heat conductivity increases heating periods for forging. For simple forgings the same forging procedure as used for commercial steels may be used, with a possible decrease in production, or a change to a heavier forging unit. For the more intricate forgings, it is often necessary to change or modify forging technique, particularly in forging operations where the more plastic steels readily flow into thin or deep impressions. The greater resistance to hot working and processing in stainless steels is reflected in a greater wear to dies and tools used in processing operations. Skill and experience are mandatory for the best results in forging operations.

Structure of Forged Olympic Bronze. Approximate composition—Cu 96.25, Si 2.75, Zn 1.00 per cent. Etchant, H_2O_2-NH_4OH. 75X. (Courtesy: Chase Brass & Copper Co.)

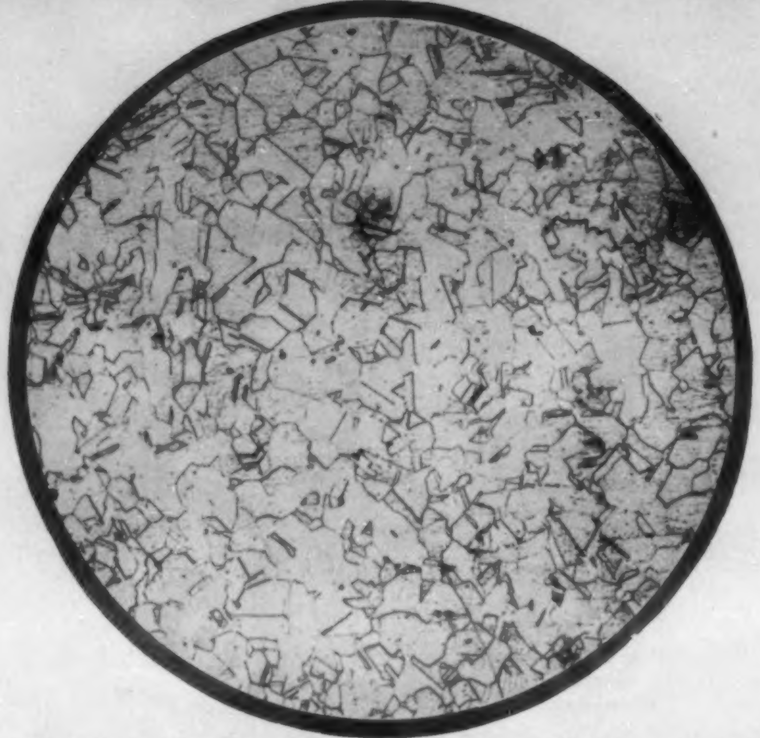




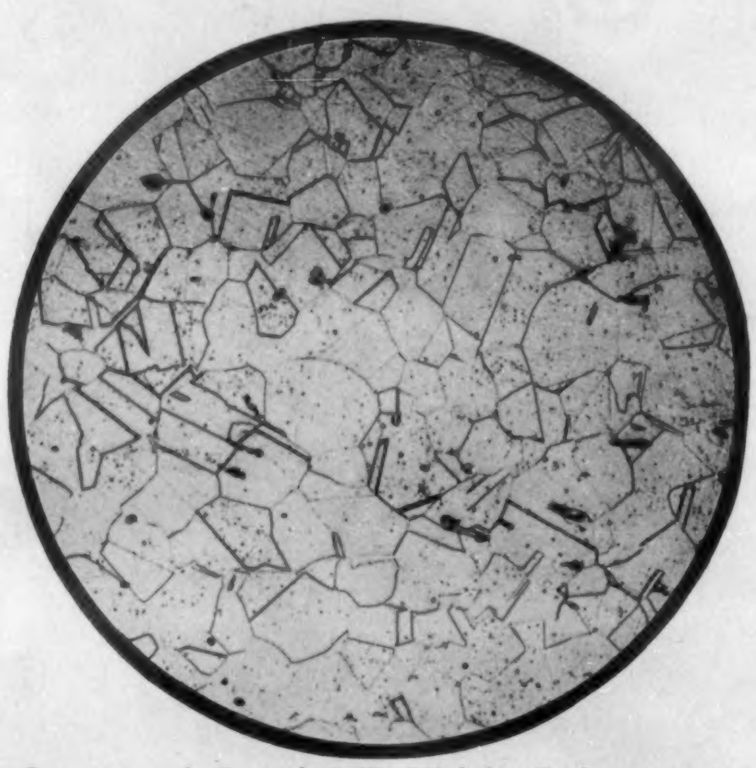
Structure of Age-Hardening Nickel-Aluminum Bronze. Approximate composition—Cu 91, Ni 7.50, Al 1.25 per cent. Etchant, H_2O_2-NH_4OH. 75X. (Courtesy: Chase Brass & Copper Co.)

Machining, in general, is more difficult on the stainless irons and steels than on ordinary commercial forging steels. Some of these steels are improved in machining qualities by the addition of free-cutting elements. These free-machining elements do not tend to impair the corrosion resisting properties of the metal under all conditions, although they do reduce the hardness somewhat in the hardenable stainless group. However, another valuable property imparted by the free-machining sulphides is a greater resistance to galling and seizing.

The non-ferrous forging metals have a wide variance in working properties. Copper and the brasses are readily forged and follow the same general forging procedure designated for carbon steel. The ease

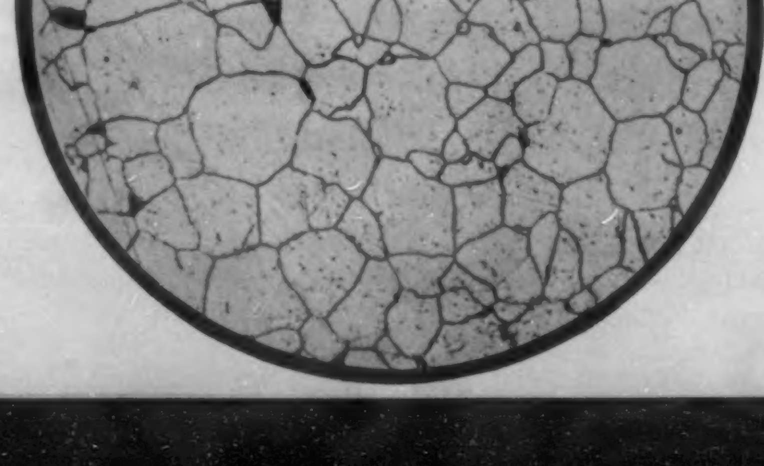


Structure of Forged Monel Metal. Etchant, 50-50 nitric and acetic acids, transverse section. Average grain diameter, 0.0010 in. 100X. (Courtesy: International Nickel Co., Inc.)



Structure of Forged "A" Nickel. Etchant, 50-50 nitric and acetic acids, transverse section. Average grain diameter, 0.0015 in. 100X. (Courtesy: International Nickel Co., Inc.)

Structure of Forged Inconel. Etchant, 10 per cent hydrochloric-electrolytic, transverse section. Average grain diameter 0.0015 in. 100X. (Courtesy: International Nickel Co., Inc.)



of working these softer metals permits the use of forging presses for small copper and brass forgings, the particular asset being that the metal can be partially extruded in the forging press operations which in turn permits the production of shapes not so easily obtained in drop forging operations on small parts. The bronzes which make use of nickel or silicon as alloying elements generally show a greater resistance to hot or cold working than do the brasses, but this is to be expected since they are stronger metals. Some of them are comparable to commercial alloy steels in their forging qualities.

The nickel and nickel-copper alloy group, as commercially pure nickel, Monel metal, and Inconel, has a greater resistance to flow in the forging operations than ordinary steels, and they are of the order of the austenitic chromium-nickel steels in forgeability.

The machining properties of the various non-ferrous forging metals show the same wide variance that are given in forging. The brasses machine quite readily, and the machining qualities of the bronzes depend upon the particular analysis. The nickel and nickel copper alloy group machine with greater difficulty than do carbon steels, their machinability being on the order of the regular austenitic chromium stainless steels.

Selection Factors

The wide array of ferrous and non-ferrous forging metals indicates some difficulty in the selection of a metal for any corrosion resisting problem. The selection of the most suitable metal must entail, necessarily, the corrosion problem first. Unless the service is of a nature that only one particular composition can be used, several factors will require consideration to make certain that the metal will render satisfactory service in the most economical manner.

Technical information is available on the ability of the various ferrous and non-ferrous metals to resist corrosion of various corroding agents and all metals that can be applied to the particular service should be considered. Particular importance should be given to the fact that atmosphere, gases, and chemicals offer certain reactions to metals in normal concentrations at room or normal temperatures and pressures, but they may have entirely different effects at elevated temperatures, high pressures, and decreased or increased concentrations. Sometimes it is necessary to use a metal that is non-magnetic. If, under the specific conditions several of the ferrous or non-ferrous metals can serve to the same practical degree from the corrosive angle, the other remaining factors should be weighed carefully.

Physical properties are important for many applications, and a comparison of strength, ductility, resistance to dynamic stresses, or resistance to wear or abrasion may be in order. The study of static and dynamic strength of the various metals may eliminate

one or more to further reduce the list. If hardness is necessary, the metals that can not supply sufficient hardness must be dropped.

Working properties are important, particularly for production processing. Ease of forging, machining, forming, and other processing must be considered as to their effect on the cost of processing operations.

Finally, but not least in importance, is the availability of a particular analysis. For quantities sufficiently large to take the product of a heat, say two or three tons, any desired standard forging composi-

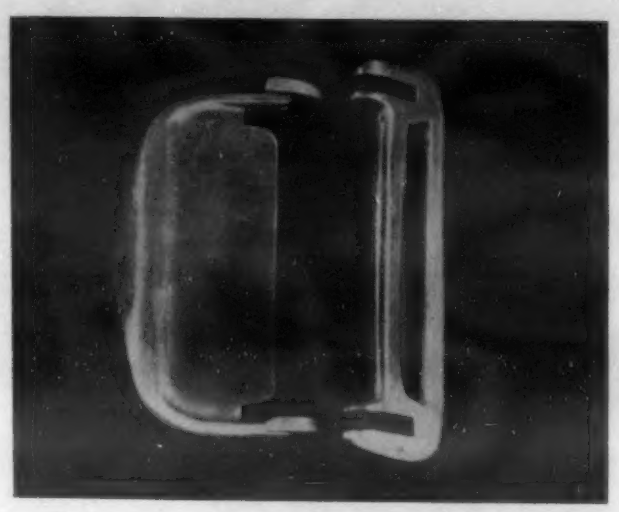
Table of Stainless Forging Metals

STAINLESS STEELS—Standard Classification

Type No.	Carbon	Chrome	Nickel	Other Elements
301X	.10-.20	16.0-17.5	7.0- 8.5	
302	.08-.20	17.5-19.0	8.0- 9.0	
302B	.08-.20	17.5-19.0	8.0- 9.0	Si. 2.0-3.0
303	.20 Max.	17.5-19.0	8.0- 9.0	S or Se .07 Min. or Mo. .60 Max.
x304	.08 Max.	17.5-19.0	8.0- 9.0	
305	.08-.20	18.0-20.0	9.0-10.0	
x306	.08 Max.	18.0-20.0	9.0-10.0	
307	.08-.20	20.0-22.0	10.0-12.0	
308	.08 Max.	20.0-22.0	10.0-12.0	
309	.20 Max.	22.0-26.0	12.0-14.0	
310	.25 Max.	24.0-26.0	19.0-21.0	
311	.25 Max.	19.0-21.0	24.0-26.0	
312	.25 Max.	27.0-31.0	8.0-10.0	
315	.15 Max.	17.0-19.0	7.5- 9.5	Cu 1.0-1.5; Mo 1.0-1.5
316	.10 Max.	16.0-18.0	14.0 Max.	Mo 2.0-3.0
317	.10 Max.	18.0-20.0	14.0 Max.	Mo 3.0-4.0
321	.10 Max.	17.0-20.0	7.0-10.0	Ti Min 4 x C
325	.25 Max.	7.0-10.0	19.0-23.0	Cu 1.0-1.5
327	.25 Max.	25.0-30.0	3.0- 5.0	
329	.10 Max.	25.0-30.0	3.0- 5.0	Mo 1.0-1.5
330	.25 Max.	14.0-16.0	33.0-36.0	
343	Over .25	12.0-16.0	12.0-16.0	W 3.0
347	.10 Max.	17.0-20.0	8.0-12.0	Cb 10 x C
403	.12 Max.	11.5-13.0		
405	.08 Max.	11.5-13.5		Al .10-.20
406	.12 Max.	12.0-14.0		Al 4.0-4.5
410	.12 Max.	10.0-13.5		
414	.12 Max.	10.0-13.5	2.0 Max.	
416	.12 Max.	12.0-14.0		S or Se .07 Min. or Mo .60 Max.
418	.12 Max.	12.0-14.0		W 2.5-3.0
420	Over .12	12.0-14.0		
420F	Over .12	12.0-14.0		S or Se .07 Min. or Mo .60 Max.
430	.12 Max.	14.0-18.0		
430F	.12 Max.	14.0-18.0		S or Se .07 Min. or Mo. .60 Max.
431	.15 Max.	14.0-18.0	2.0 Max.	
434A	.12 Max.	14.0-18.0		Si 1.0; Cu 1.0
438	.12 Max.	16.0-18.0		W 2.5-3.0
439	.50-.65	8.0		W 8.0
440	Over .12	14.0-18.0		
441	Over .15	14.0-18.0	2.0 Max.	
442	.35 Max.	18.0-23.0		
446	.35 Max.	23.0-30.0		
501	Over .10	4.0- 6.0		501 & 502 are available with suitable proportions of W, Mo, Si, and other elements.
502	.10 Max.	4.0- 6.0		

NON-FERROUS METALS—General Classification and average proportions of identifying elements.

Name	Copper	Zinc	Nickel	Other Elements
Copper	99. plus	..	..	
Forging Brass	60.	38.	..	Pb. 2.
Muntz Metal	59.	41.	..	
Naval Bronze	59.	38.	..	Pb. 2.; Sn 1.
Manganese Bronze ..	57.	40.	..	Sn 1.4; Fe 1.4
Silicon Bronze	96.	..	..	Si 3.; Mn 1.
Nickel Al. Bronze ..	92.	..	4.0	Al 4.
Aluminum Bronze ...	92.	..	..	Al 8.
Beryllium Copper ...	97.4	..	0.4	Be 2.2
Nickel	..	..	99.0	
Monel Metal	33.	..	67.0	



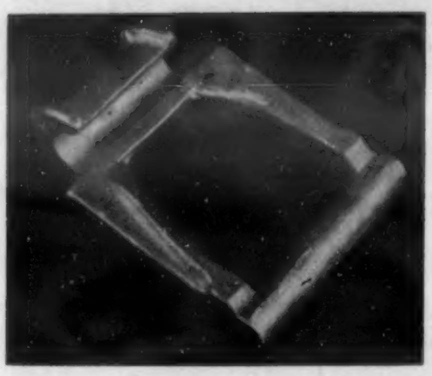
Type 401 Stainless (Ferritic Chrome) Bracket Forgings.

Type 414 Stainless (Ferritic Cr-Ni) Valve Seat Forging.

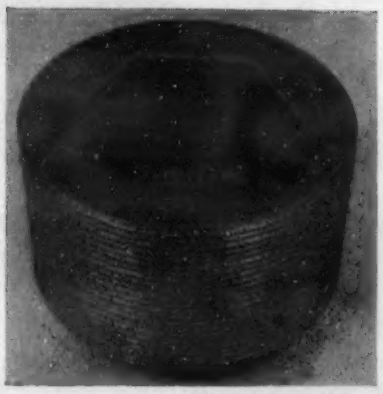
Type 303 Stainless (Austenitic) Valve Body Forging.

A 55-Lb. Naval Bronze Drop Forging.

A Silicon Bronze Valve Seat Forging.



Monel Metal Drop Forged Chain Link.



Type 325 Stainless (Austenitic) Forged Still Plug.

tion can be obtained in a reasonable period. For smaller quantities, all of the popular much used standard analyses are either in the steel storage stock of forging concerns specializing in stainless forgings, or they can be secured readily. Where a size and grade is procured in large quantities, forgings in that grade can be produced economically. Special analyses and little used compositions are sometimes hard to secure on short notice, and wherever possible, one of the standard much used grades should be specified to save time and secure economical forgings.

The metal selected will be the composition which produces satisfactory service for the specific conditions at the most economical overall cost. In considering the cost of the stainless forging, the first requisite should be that of quality, for stainless metals are sensitive to treatment. Good treatment, in the form of experience and modern forging equipment will develop the properties that the alloys have imparted to the metal. Poor treatment, in the form of inexperience, careless, or poor equipment can increase greatly the cost of a supposedly economical forging by developing poor structure, defects, and a large percentage of expensive scrap. The experienced producer of stainless metal forgings uses every modern device, technical knowledge, and practical experience to impart quality to the forged product, and it has been largely through such development that the phenomenal increase in the use of stainless forgings has been attained during the present period.

Analysis for Lead in Carbon Steel

by A. E. PAVLISH, J. D. SULLIVAN and JAMES SHEA

Battelle Memorial Institute, Columbus, Ohio

THE INTENTIONAL INTRODUCTION of lead to plain carbon steels[1] has added another element that the analytical chemist must determine, sometimes even in routine work. The fact that it is present in small amounts, usually in the range of 0.10 to 0.30 per cent in free machining steels, makes the analysis more difficult.

The chemical laboratory of Battelle Memorial Institute has been analyzing lead-bearing steels for several years and has spent considerable effort in developing a method that is accurate and not too time consuming. During the last few months, lead-bearing steels have become quite common commercially, and since a large number of requests have been received to outline the methods of analysis used at Battelle, this paper is written.

Many methods were investigated, but the gravimetric method outlined in this paper was found to have general applicability, and is recommended for most types of work. The authors are working on the development of a colorimetric method and plan to publish a paper on it as soon as all the kinks are ironed out.

Experimental Work

Lead in steel may be determined gravimetrically as $PbSO_4$, $PbCrO_4$, or $PbMoO_4$. Electrolytic precipita-

tion of lead anodically as PbO_2 is common in the analysis of bronzes, and has been used to a limited extent in the determination of lead in steel. Experience with the lead sulphate method has proved that it is the least troublesome, and as reliable as the other gravimetric methods.

Lead is separated from iron by precipitation as sulphide. Concentrations of free mineral acid greater than 0.2 normal may prevent complete precipitation. The procedure outlined below, if properly carried out, gives a solution of proper acidity:

Reagents:

Hydrochloric acid ...	1 part HCl, 5 parts H_2O, by volume.
Nitric acid	1 part HNO_3, 1 part H_2O, by volume
Sulphuric acid	1 part H_2SO_4, 1 part H_2O, by volume.
Ethyl alcohol	95 per cent
Wash solution	3 parts H_2SO_4, 97 parts H_2O by volume saturated with $PbSO_4$

Procedure:

Transfer a 5-gram sample to a 600-ml. beaker, add 100 ml. 1:5 hydrochloric acid, and cover with a watch glass. Heat on a hot plate until dissolution of the sample is complete, and dilute to approximately 350 ml. with hot water. Saturate the solution with H_2S by passing a rapid stream of gas, preferably compressed tank H_2S, into the solution for approximately 3 mins. Filter the solution (ordinarily filtration can be done immediately) through a Whatman No. 41 paper or equivalent, and wash the residue and paper with water saturated with H_2S. Transfer the paper and precipitate to the original beaker and cover with 50 ml. 1:1 HNO_3. Boil until dissolution of the precipitated sulphides is complete. Filter through a Reeve Angel No. 711 paper or equivalent, and wash the paper thoroughly with hot water, keeping the volume as small as possible. Add 20 ml. 1:1 H_2SO_4 to the filtrate and evaporate to copious fumes of SO_3. Cool, dilute with 150 ml. water and boil to effect complete dissolution of the salts. Cool again, and add 50 ml. alcohol. Transfer the solution to an Erlenmeyer flask and shake for 10 to 15 mins. by hand or in a laboratory shaker or, if speed is not essential, allow to stand for several hours. Filter the $PbSO_4$ either on a Whatman No. 44 filter paper, or a weighed Gooch crucible, and wash with dilute H_2SO_4 (3:97) which has been saturated with lead sulphate. Wash two times with alcohol. If a Gooch crucible is used, dry to constant weight at 105 to 110 deg. C.; if a filter paper is used, transfer to a Battersea or weighed porcelain crucible and ignite at 450 to 500 deg. C. Platinum crucibles are not recommended for the ignition of the filter paper containing $PbSO_4$ because of the danger of contaminating the platinum with lead.

$$PbSO_4 \times 0.68326 = Pb$$

Discussion of Results

The accuracy of the method was determined by analyzing synthetic samples prepared by adding increments of lead as lead nitrate to Bureau of Standards Steel No. 55a dissolved in the manner described. The accuracy of the results is shown in Table I, and the precision that can be expected in Table II.

The method has been used in different laboratories on the same sample of steel, with excellent agreement. As an example, Battelle found 0.21 per cent Pb and the laboratory submitting the sample reported 0.20 per cent Pb.

Table I.—Results Obtained by Battelle Procedure on Synthetic Samples

Weight of Sample, grams	Lead, per cent: Added	Found	Error
5	0.008	0.009	+0.001
5	0.018	0.018	0.000
5	0.096	0.096	0.000
5	0.191	0.193	+0.002
5	0.382	0.371	—0.011

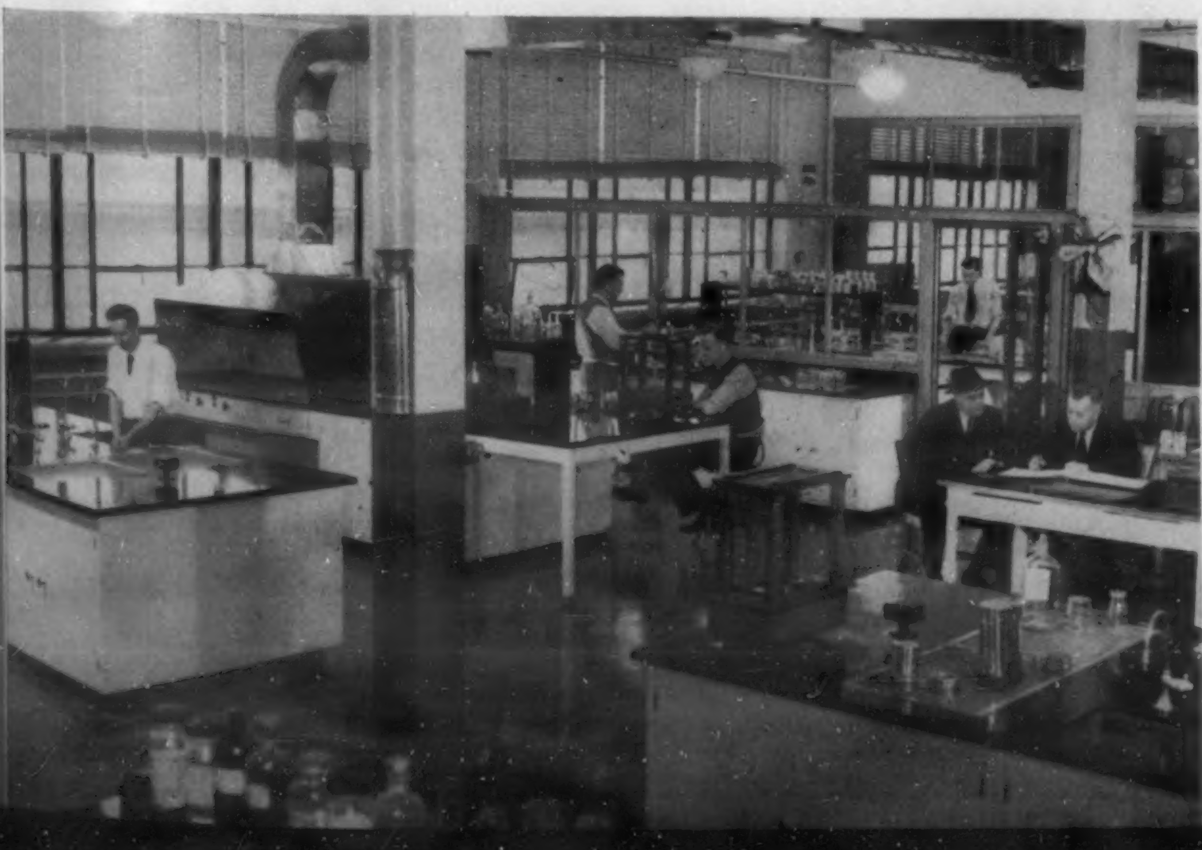
Table II.—Results by the Battelle Procedure on Lead-Bearing Steel Samples

Sample	Weight of Sample, grams	Lead, Per Cent: Results		Average	Average Deviation
A	5	0.030	0.027	0.029	0.002
B	5	0.068	0.066	0.067	0.001
C	5	0.074	0.072	0.073	0.001
D	5	0.103	0.103	0.103	0.000
E	5	0.184	0.184	0.184	0.000
F	5	0.188	0.185	0.187	0.002

Reference

[1] J. H. Nead, C. E. Sims & O. E. Harder. "Properties of Some Free-Machining, Lead-bearing Steels." *Metals and Alloys*, Vol. 10, Mar. 1939, page 68; Apr. 1939, page 109.

Note: Since this article was written analytical methods were outlined by G. E. F. Lundell and C. M. Johnson for lead in carbon and alloy steels in the April, 1939, issue of "Metal Progress," pages 383-384.

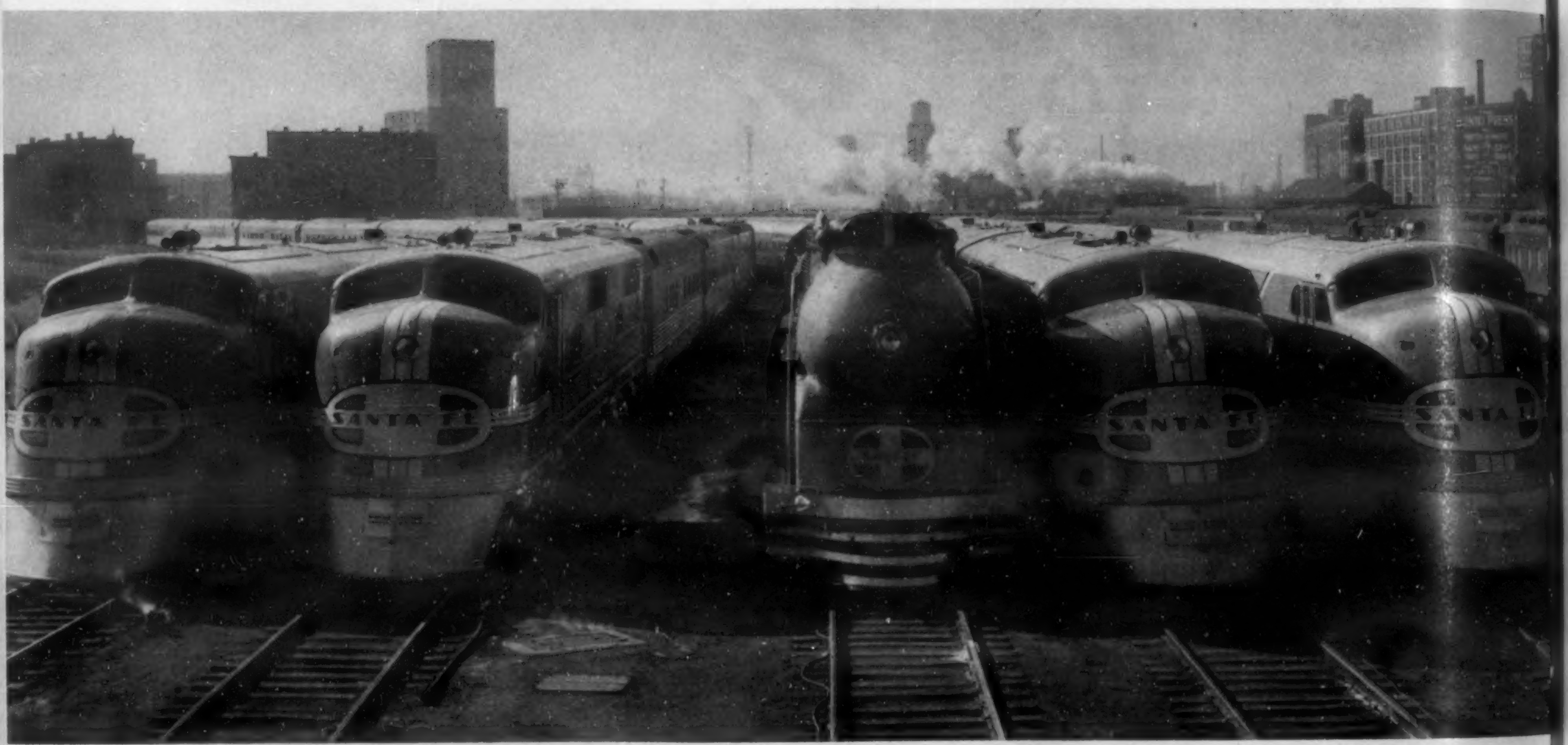


General View of Chemical Laboratory, Buick's Metallurgical Division (Courtesy: General Motors Corp.)

European and American Rail Service Problems

—TWO EXTENDED ABSTRACTS

by H. W. GILLETT



Five of Santa Fe's New Streamlined Fleet, which Travel at High Speed over Modern Rails.

Few metallurgical matters touch the average man so significantly and yet so subtly as do the problems associated with rail steels and their service. Comfortable Pullman passengers, breathless suburban commuters, jostled subway sufferers and dusty rod-riders travel in complete safety and unconcern over thousands of miles of rail each day—a safety and an unconcern that are a tribute to the metallurgical engineer's persistent probing of service factors, of methods of detecting potential rail failures, and of enlightened maintenance of way practice.

That investigation of rail metallurgy and performance has been vigorously pursued both in Europe and in America is evident in the collection of papers presented before the recent "International Rail Assembly" at Düsseldorf, and in the last Progress Report on rail fissures of the University of Illinois, each of which is reviewed separately in the two extended abstracts presented herewith.

The Editors.

AN INTERNATIONAL DISCUSSION OF RAILS

THERE was held in September, 1938, in Düsseldorf, a so-called "International Rail Assembly", under the auspices of the Deutsche Reichsbahn and the Verein deutscher Eisenhüttenleute. This was the fourth such meeting, held at 3-yr. intervals. Out of 34 papers presented, one was from England and one was a motion picture of rail welding in the U.S.A.; all the others were by Continental authors. In view of the different traffic conditions abroad, and the differences in rail weight and composition from those here, it is questionable how direct the application of Continental experience and opinions may be to American conditions. Nevertheless, if the differences are kept in mind, the discussion should be of value to American producers and users of rails. Some of the metallurgical high spots will therefore be abstracted from the preprints.

As E. H. Schulz pointed out in the opening paper, the rail is a metallurgical achievement and a metallurgical problem. Perhaps the primary problem abroad is the development of a more wear-resisting rail. A duplex rail in which the top of the head is 12% Mn steel, the balance soft steel, has been applied to some extent for this purpose. Building up wear resistance by raising the carbon content (i. e., using the American rather than the European range of composition) is deprecated as requiring too much care in manufacture, so attention is called to building up the phosphorus instead. That phosphorus leads to brittleness (as taught in the schools) is considered to be overbalanced by the freedom from defects, because of the lower oxygen content in presence of high phosphorus, and it is pointed out that Bessemer rails (of course with relatively low carbon) containing 0.10 percent phosphorus, have a good record for freedom from breakage. However, the development of a lightly alloyed rail that will be tough at—20 deg. C. is listed as a desirable goal.

The difficulty of making tests that truly represent rail service is mentioned and a plea made for further development of suitable wear testing.

Three papers dealt with warping of track composed of long welded rail under thermal stress. Apparently the Continental rail is not so suitable as the American for such track. A rail of high yield strength, yet tough at low temperature is needed. Freedom from internal stress is also desired. Mechanical devices for fastening the rail to the bed are proposed to palliate the difficulties.

Wear of Rails

More papers dealt with rail wear than with any other general topic. C. J. Allen of the London & North Eastern Railway, in the lone English paper describes the fluctuating ideas as to composition. The present basic open hearth rail on the L. & N. E. carries 0.55 C, 0.13 Si, 1-1.10 Mn, 0.04 P, and 0.04 percent S and shows 120,000 lbs. per sq. in. tensile strength, 18 percent elongation, and 29 percent reduction of area; this represents an improvement in ductility over a previous 0.61 C, 0.70 percent Mn rail. The rails are slow cooled by the Sandberg method. With controlled cooling the reduction of area of the 0.55 C, 1.10 percent Mn rail averages 36 percent. A trial has been made of a 0.44 C, 1.50 percent Mn rail, but the wearing properties were not considered enough better to justify the cost of the increased manganese. For severe service where wear resistance is imperative, rails heat-treated by the Sandberg "sorbitic" process,—i.e., by applying a regulated amount of water mist to the rail head at 780-850 deg. C. under high pressure for 15 sec., and lower pressure for the next 20 sec., then cooling to 550-600 deg. C., from which the rail is slow cooled down to 300 deg. C.—is becoming standard. A production of 20,000-25,000 tons per year of "sorbitized" rails is regarded as certain.

The head is increased in Brinell hardness from 230 to 320, and this results in reducing the rate of wear by roughly 50 per cent. A comparison has been made on 1,000 tons of untreated open hearth chromium rail steel with 0.51 C, 0.21 Si, 0.86 Mn, 0.04 P, 0.045 S, and 0.96 percent Cr against the "sorbitic" 0.49 C, 1.14 percent Mn acid Bessemer rails. There is very little difference in the tensile strength and ductility, the sorbitic rail being a shade the better and having a slight superiority in wear resistance. The choice seems to be made on the basis of 20 percent increased cost for the chromium rail against 12 to 15 percent for the treated medium-manganese.

For street railway service, the importance of maintaining the largest feasible contact surface between rail and wheel, and the severe wear caused by braking, are stressed by H. O. Lange. R. Kuhnel depicts some interesting cases of rippled wear on street railway rails and considers the possible causes without coming to a conclusion as to the primary cause.

Rail Testing

Siebel gives a general discussion of wear testing, without being at all specific as to what method would correctly appraise a rail. Eichinger describes various tests made with apparatus of the Amsler type and concludes that laboratory wear tests may mean something provided that the worn test surfaces resemble closely those produced on the rail and wheel by actual service. Bradenberger reports studies by X-ray methods on the grain size and lattice disturbances in vari-

ous types of rails, and upon worn surfaces. So far this method of study doesn't seem to be getting anywhere.

A dozen rails broken in service, one in 2 yrs., the others in 23 to 57 yrs. were examined as to notched bar impact. Most of these were Bessemer rails, some with only about 0.20 percent C, others up to 0.40 percent C, while the 2 yr. break was in 0.63 C, 0.60 percent Mn open hearth rail. Some of the old rails had an unsound structure. With this heterogeneous lot of varying compositions and soundness it was found that impact data bore no relation to the life. The service must also have varied and cannot have been very severe on the rail that lasted 57 years.

Mandel, however, testifies that on the Hamburg elevated, where Bessemer rail was used up to 1913, those rails wore less than the later-used open hearth rails. (Traffic density comparisons are not given). Finally, on the curves the situation became so acute that duplex rails with hard heads (it is not stated whether the head was the 12 percent Mn referred to by Schulz or the eutectoid head discussed by Ros and Bianchi) were used, since early Sandberg rails tried were full of tiny checks in the head and there was too much rail breakage with them, so the choice in Hamburg has been between the untreated rail and the duplex. On curves the duplex rail outlasts the ordinary rail by 4 to 1. On the basis of experience with 2000 tons of duplex rails it is concluded that although the first cost is doubled, the final overall cost is halved.

M. Ros and A. Bianchi of the Swiss Materialprüfungsanstalt present a copiously illustrated discussion of laboratory testing of rails, upon European type rails, some normal, some with "sorbitic" heat treatment, some quenched and drawn, others of eutectoid structure, and duplex rails with soft base and eutectoid head. Some examples of the eutectoid head run 0.60-0.65 C, 0.60-0.80 Mn, 0.25-0.35 Si, 0.80-1.00 Cr, with or without 0.15-0.25 percent Mo. It is concluded that the static bend test could satisfactorily be substituted for the drop test, a statement which recalls that of H. F. Moore (in the 4th Progress Report of the Joint Investigation of Fissures in Railroad Rails, a review of which follows this abstract) that "studies of acceptance tests for rails have led to the conclusion that a bend test in a testing machine is a better test than the present standard drop test."

Studies of internal stress in the various types show most stress in heat treated rails, but it is concluded that this has no practical effect upon service. Amsler wear tests and observations on service wear show good correlation. At a given Brinell the heat-treated rails wear less than those of the same hardness in the as-rolled condition. In the heat-treated rails the wear decreases slowly with increasing hardness to 350-400 Brinell and then decreases abruptly. In the as-rolled steels the break in the curve comes at about 275-300 Brinell, with wear decreasing faster than the hardness increases above that point. Changes in metallographic structure, of course, explain these breaks in the curves.

With proper manufacturing technique rails safe against breakage can be made in any of the varieties mentioned above. For severe service the authors consider that a mildly alloyed steel containing silicon and chromium, with carbon not over 0.40 percent, heat treated by quenching and tempering to 350-420 Brinell, will find increased favor. Another paper on rail testing by Kuhnel of the Deutsche Reichsbahn was presented but not preprinted.

R. Walzel reports successful use in Austria of rails of 0.60 C, 1.80 percent Mn, made in the electric arc furnace. For crossings, the same steel, oil quenched and drawn, is used. Copper additions are being tried in this steel to reduce corrosion in tunnels. No low temperature brittleness has been evidenced in the Mn rails under winter service conditions.

The problem of rail corrosion in tunnels is discussed by J. Friedli. Copper-bearing rails, which show up better in the open air, are considered generally less resistant in damp and smoky tunnels. The data on which this statement is based are for 4 and 8 mos. exposure. In view of this short exposure and of the irregularities in the tests, these and other conclusions drawn (e.g. that heat-treated rails resist corrosion in tunnels better than non-heat-treated ones) do not appear very convincing. Other conclusions are drawn from laboratory corrosion tests of a type not related to rail service.

Long Welded Rails

J. Nesmedy-Nemesek discusses the testing of welded rails. Like Ros and Bianchi he favors a static bend test over the drop test. L. Benesch argues in favor of electric arc welding as compared with other welding methods for rails, while J. Wattmann favors thermit welding, and J. E. Languepin argues for electric butt welding. D. von Csillery and L. Peter studied resistance and arc welded rails and conclude that arc welding should be done automatically rather than by hand. R. Dumpelmann argues for oxy-acetylene welding. One might draw the conclusion that regardless of differences of opinion on the welding method to be chosen, there must be a considerable degree of agreement among Continental railroad men as to the value of long rails.

There seems to be reflected in these papers a willingness to use a more expensive rail to combat wear under severe conditions. Use of alloyed and heat treated rails seems far more advanced or at least the railroad officials far more willing to give such materials a real trial than is the case in this country.

Papers in the Symposium

Stresses and Their Effects on Track

M. T. Huber. "Ueber den Einfluss der Wärme-

spannungen auf die Verwerfungsgefahr eines geraden lückenlosen Gleises." 4 pages.

Friedrich Raab. "Das Eisenbahngleis unter dem Gesichtspunkt der Verwerfungssicherheit." 10 pages.

W. Hüttner. "Die Wirkung der in Vignol-Langschienenbahnen entstehenden Spannungen auf den Oberbau." 6 pages.

Mechanical Wear and Tear

Camillo Zocchi. "Sulla teoria dell'usura meccanica dei metalli." 4 pages.

Erich Siebel. "Der Einfluss der Versuchsbedingungen bei der Verschleissprüfung." 4 pages.

Anton Eichinger. "Abnützungsversuche mit Schienen- und Radreifenstählen." 3 pages.

E. Brandenberger. "Röntgenographische Kennzeichnung von Schienenwerkstoffen." 4 pages.

H. O. Lange. "Die Abnutzung der Schienenfahrfläche bei Strassenbahnen." 6 pages.

Reinhold Kühnel. "Untersuchungen an Riffelschienen." 6 pages.

Operating Experiences

J. Bartel. "Kerbzähigkeit im Betrieb gebrochener Eisenbahnschienen." 4 pages.

Georg Mandel. "Was lehrt die Auswertung einer 25 jährigen Statistik über die Liegezeiten von Schienen?" 4 pages.

Gottfried Kühn. "Betriebserfahrungen mit Rillenschienen im Strassenbahnbau." 4 pages.

Testing and Inspection

M. Ros & A. Bianchi. "Prüfung im Laboratorium und Erfahrung mit Einstoff-, Zweistoff- und wärmebehandelten Schienen." 23 pages.

C. C. Teodorescu & St. Nadasan. "Ueber den zahlenmässigen Vergleich der Seigerung in Walzprofilen." 4 pages.

Welding

J. Nemesdy-Nemesek. "Ueber einheitliche Bedingungen für Prüfung und Abnahme geschweisster Schienenstösse." 5 pages.

Franz Benesch. "Ungleichmässigkeiten der Schienenschweissung." 6 pages.

John Wattmann. "Aluminothermische Schweissung im Langschienenbau und im lückenlosen Gleis." 8 pages.

J. J.-E. Languepin. "Essais sur la Soudure Électrique par Résistance des Rails." 6 pages.

D. v. Csilléry & L. Péter. "Vergleichende Untersuchung handgeführt oder automatisch elektrisch geschweisster harter Schienenstähle." 9 pages.

R. Dümpelmann. "Die Entwicklung der autogenen Schienenstossschweissung." 4 pages.

General

C. J. Allen. "The Exceptional Wearing Properties of Early Steel Rails and their Reproduction in Modern Rail Manufacturing Conditions." 10 pages.

Richard Walzel. "Fortschritte an Eisenbahnoberbau-Stählen in Deutsch-Österreich." 6 pages.

J. Friedli. "Vergleichende Korrosionsversuche mit Schienenstählen." 8 pages.

R. V. Baud. "Zur Ermittlung des günstigsten Stegprofils von Eisenbahnschienen." 4 pages.

AMERICAN INVESTIGATIONS ON RAILS

THE Association of American Railroads and the Rail Manufacturers' Technical Committee are sponsoring extended investigations looking toward the betterment of rails, both from the point of view of safety of the travelling public and the operating personnel, and the reduction of rail cost per ton mile. The work is under the able direction of Professor H. F. Moore, at the University of Illinois, with Professor H. R. Thomas as general engineer of tests and in immediate charge of field tests; Asst. Professor R. E. Cramer, metallurgist; Mr. N. J. Alleman in charge of end-batter tests and drop and bend tests of rail; Mr. S. W. Lyon in charge of tests of specimens of rail steel; and Mr. J. L. Bisesi in charge of tests for detecting cracks in rails.

Because the present plight of the railroads affects general recovery and hence the welfare of every one, the economic aspect almost as much as the safety aspect makes these investigations of vital import to every one, and especially to the metallurgical engineer, who has both a personal and a professional interest in the progress being made. Since the problems are long range and the work continuous, in abstracting the results, not only the last formal report,[1] but its predecessor,[2] as well as a separate publication on one detail,[3] will be considered as a unit. While the titles feature fissures, the work has many other angles.

Shatter Cracks

The present argument in regard to fissures is that some rail heats show shatter cracks, which, under high wheel loads start to develop as fissures, with repeated wheel loads and bending stresses both acting to cause further growth.

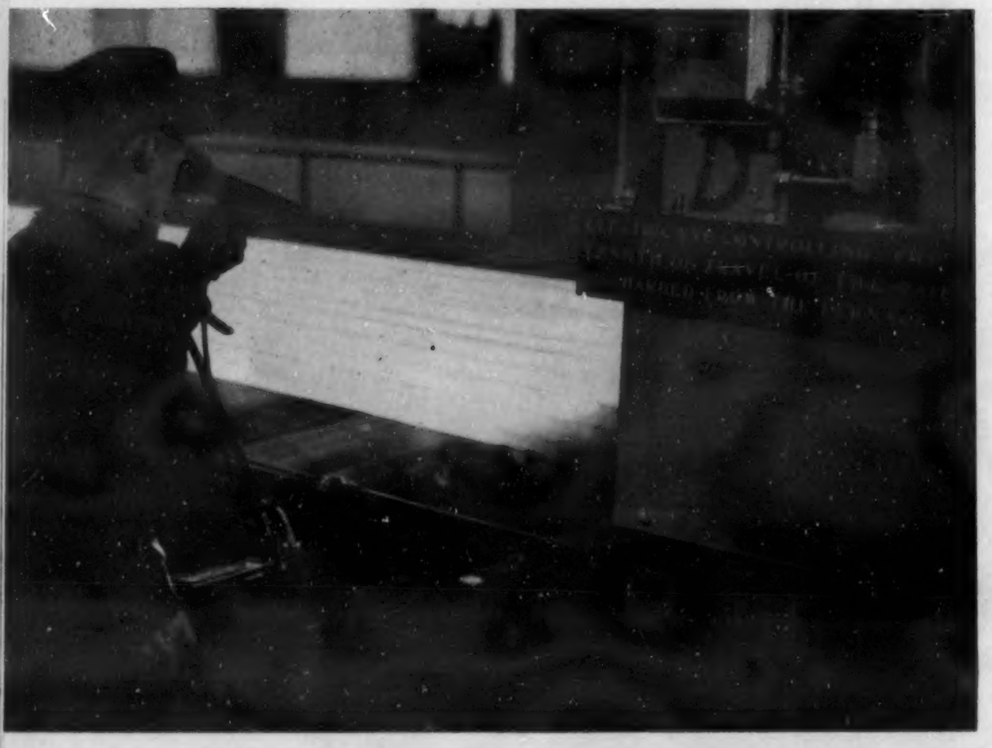
Factors in the whole engineering appraisal therefore involve determination of wheel loads and bending stresses in track, testing methods for determination of the presence of shatter cracks in new rails, detector car methods for showing up fissures in rails in service, and, still more fundamentally, methods for prevention of susceptibility to shatter cracks and curative measures for prevention of their formation in susceptible heats.

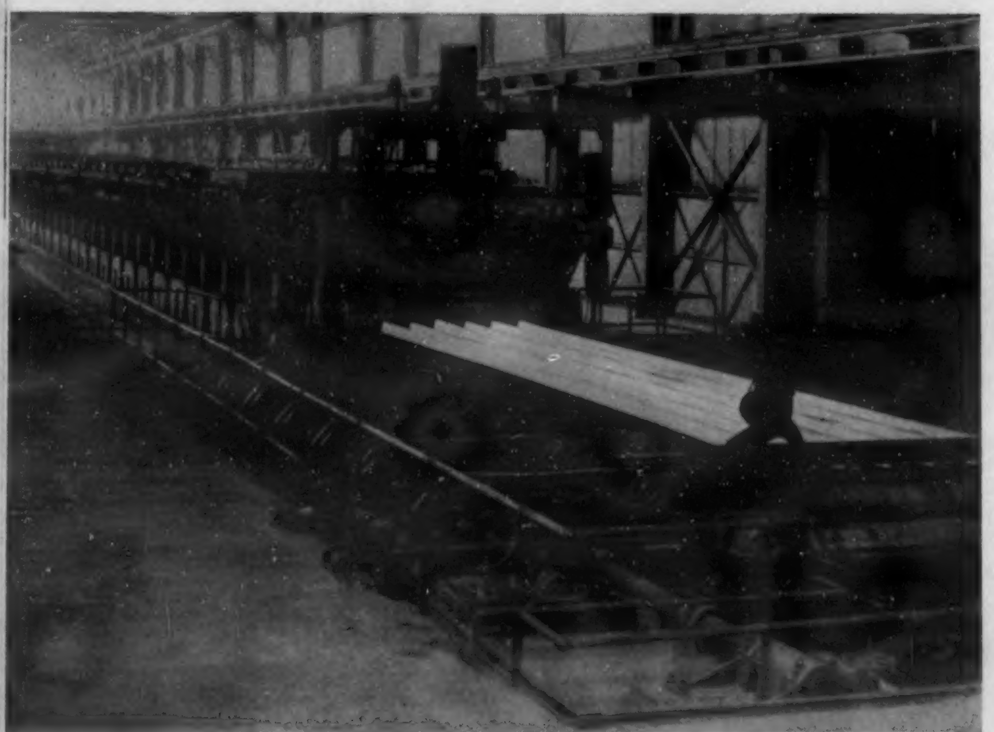
Approximately 1 heat in 50 shows shatter cracks when no special precautions are taken to prevent

Right: One Step in Rail Heat Treatment (Courtesy: Bethlehem Steel Co.)

Below: Taking Temperature of Rails as They Leave a Brunorizing Furnace at the Gary Works of the Carnegie-Illinois Steel Co.

A Charge of Six Rails Emerging from the Brunorizing or Heat-Treating Furnace at the Gary Works of the Carnegie-Illinois Steel Corp.





them, and about 1 wheel load in 1000 is of sufficient intensity, i.e., 40,000 lbs. or higher, to develop a shatter crack into a fissure. [Further studies in inertia effects in rail make it seem probable that the latter figure may be something like 1 in 500.] That attention to prevention of causes for failure, and previous detector car runs is proving helpful is shown by detector car runs over 6,293 test rails of the A. T. & S. F., and 3,207 test rails of the B. & O., all of which had carried heavy traffic without finding a fissure. Two transverse fissure failures in service occurred, both from two heats that had shatter cracks; both of these heats had been picked out by detector car runs the previous year. Additional detector car runs over this section found six more fissured rails, all from the same two heats. The earlier evidence of direct connection between shatter cracks and fissures is thus reinforced.

Track stresses, the effects of flats on wheels, and of low spots and hard spots in rails have been studied

in an effort to secure data helpful to the maintenance gang in avoiding the local development of high stress.

Low temperature fatigue tests indicated that, despite the differences in impact resistance, fatigue failure of rail steel is not likely to be more readily developed at low than at normal temperature. For detection of shatter-cracked rails by acceptance tests, a static bend test, head down, is considered more revealing than the regular drop test. Sound transmission and damping test methods, tried out as possibilities of non-destructive methods, have not yet been perfected sufficiently to pick out shatter-cracked rails. Some remaining possibilities for improvement are still on the program.

Slow Cooling of Rails

It is rather well established that shatter-sensitive rails can be prevented from actually cracking by controlled slow cooling. Different mills have adopted different rates of cooling, and stop the slow cooling at different temperatures. Preliminary tests aimed to point out more clearly the limiting rates and temperatures have been made and, so far, indicate that some of the cooling schedules might perhaps be made less severe. On so important a matter it is necessary to make haste slowly, so more tests are scheduled before releasing the present data or advocating changes.

Although the efficacy of slow cooling is established, the understanding of the mechanism by which the slow cooling exerts its effect is still very hazy. That hydrogen may be the culprit and that the function of slow cooling is to allow it to escape has been suggested in relation both to "flaky steel" and to shatter cracks. The presence of water vapor in the open hearth atmosphere and its reaction with iron to form iron oxide and free hydrogen of course offers a mechanism for presence of that gas, though why it should be absorbed in such variable fashion is not evident. In order to put hydrogen into the steel, in fashion more analogous to practice than the former trials of heating solid rails in the gas, it was bubbled through the molten ingot. Rails from this ingot developed shatter cracks, on uncontrolled, hot-bed cooling, and the cracks were avoided by the regular slow cooling practice.

This reviewer doubts whether hydrogen, unassisted, will cause cracks and flakes, and feels that the possibility of treating the heat so that it is not sensitive to hydrogen is not being given due attention, but as soon as hydrogen is generally accepted as being one of the links in the chain, this further point will logically bring itself to light.

End Batter

A field of work covered, but not indicated by the titles of the reports, is that of avoidance of end batter, i.e., pounding down of the rail ends as the wheel passes over a joint. This is irritating, rather than dangerous from the safety point of view, as it is an important factor in maintenance of way cost, and calls for attention primarily from the economic aspect. When the rail ceases to give a smooth ride it should be repaired or replaced.

The difficulty may be avoided by using long lengths of jointless, welded rail, and that is, of course, being actively studied by the railroads. Pending the adoption of such an expedient, something has to be done about the ends of rails of ordinary length. Exhaustive study is being put on a whole series of possible means for local heating of the rail head at the end of the rail, and of various quenching media, ranging from the cooling power of the adjacent metal to air blast and water. Some of these means are suitable for use in the mill, and some may be applied in the track; hardening of ends of new rails in track is quite common. Most of the processes materially improve the hardness and resistance to batter at the joints without harming toughness, and, apparently, reasonable care will avoid a poor transition zone that would cause shelling off of the hardened zone, a possibility that has been feared by some. Water quenching applied to built up welded ends, ground down and heated by oxyacetylene for hardening, or mere welding without subsequent hardening, decreased the toughness. The indications are that mill treatment to make the ends hard from the start will be more advisable than letting the ordinary soft rail end wear down until something has to be done about it before attempting to harden the end. The tests of rails with built-up ends so far carried out, however, are not numerous enough to form a basis for conclusions.

Rolling-load tests are being developed as a means of laboratory evaluation of the merits of end hardening processes, but they are not yet perfected, nor is any attempt made to differentiate among the more promising end hardening methods, although some indications of a minimum effective (Brinell or Rockwell "C") hardness have been shown.

All in all, the work shows encouraging progress, and the reports show a true engineering spirit in recording results obtained, but refusing to draw sweeping and binding conclusions till everything has been checked and double checked. By the very nature of rail service, results of practical tests are slow in accumulating. Research in this field is a job for patient men.

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PART 1

Fatigue of Metals —Developments in the United States

by H. F. MOORE

Research Professor of Engineering Materials, University of Illinois, Urbana, Ill.

Fatigue of Metals—The M.I.T. Conference: In 1937 the Massachusetts Institute of Technology held a "Summer School" in which a month's study was devoted to fatigue of metals and to creep of metals at high temperature. Distinguished guest lecturers and the M.I.T. staff conducted the courses. At the end of the session, all-day Conferences were held on each subject, in which engineers who are deeply concerned with these topics presented their summation of the way the problems affect their own industry.

The papers on creep were in general of a rather specialized nature and most of them were by authors who have given somewhat similar discussions elsewhere. The papers on fatigue, while dealing with rather specific problems are of very general application to metallurgical engineering. Through the courtesy of Prof. J. M. Lessells of M.I.T., arrangements have been made for publication in METALS AND ALLOYS *of the fatogue papers.*

These are, beside the introductory paper by Prof. H. F. Moore, University of Illinois, here given:

"Fatigue Problems in the Electrical Industry," by R. E. Peterson of Westinghouse.

"Fatigue Problems in the Electrical Industry," by K. Arnstein and L. E. Shaw of the Goodyear Zeppelin Corporation.

"Fatigue Problems in Structural Designs," by A. V. Karpov, Chairman, Committee on Fundamentals Controlling Structural Design, A.S.C.E.

"Fatigue of Light Metal Alloys," by R. L. Templin, Aluminum Company of America.

"Fatigue of Metals in Some Problems of the Railroad Equipment Industry," by R. W. Clyne, American Steel Foundries.

These will be published in later issues. Some of them have been revised to date.

An interesting thread of continuity runs through all of these, namely that the endurance limit of a metal under ideal conditions of lack of stress-raisers, i.e., on a polished specimen, while readily determinable in the laboratory, tells little of engineering value save the maximum stress that can be withstood under ideal conditions. The real value of the study of fatigue has been to make the engineer re-examine his designs and the conditions of service in the light of stress concentration. He has been forced to realize that it is the true stress at the point of highest stress concentration, whatever it may be that produces that concentration, that is the determining factor and as a result, he knows very much more about stress localization than he did before. He is more likely to cast out the beam of stress concentration by proper design on his part and by insistence on proper metallurgical processing to avoid damaging the surface, than to throw the blame on some alleged failure of a given lot of metal to show its normal fatigue resistance.

The metallurgist, too, has become acquainted with the propensity of very hard materials toward notch propagation, and is beginning to evaluate metals in relation to this propensity.

Study of the whole series of articles should be helpful both to those who use metals under repeated stress, and those who make and treat the metals.—The Editors

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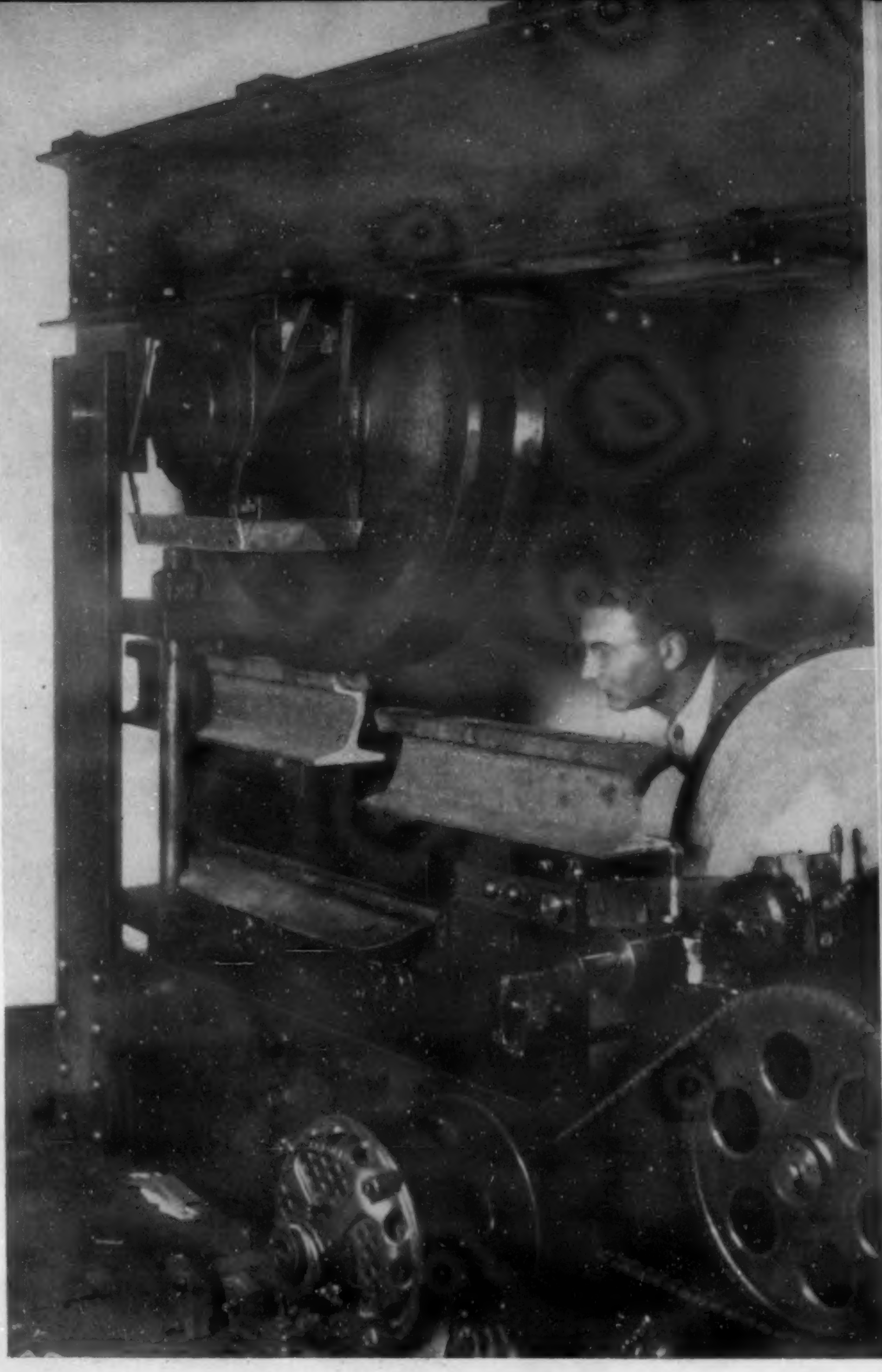
NO ONE MAN CAN GIVE a comprehensive discussion of the recent developments in this country in the study and application of the principles of the behavior of metals under repeated stress,—commonly called the "fatigue" of metals. This paper will discuss only some of the high points in this development, as the writer sees them. In particular, no discussion will be given of the phenomenon of corrosion-fatigue, not because this subject is unimportant—it is vitally important, but because it is discussed in other papers by our leading worker in that field, Dr. D. J. McAdam, Jr.

Endurance (or Fatigue) Limit—Significance and Limitations

The outstanding result commonly obtained from a series of tests under repeated stress is the endurance limit—that stress below which the metal can, presumably, be subjected to an indefinitely large number of cycles of stress without developing a progressive fracture. (The significance of a limiting stress for a definite number of cycles is discussed in a subsequent section of this paper.) This limiting stress is a significant property of the metal, but it must always

"Rolling-Load" Fatigue Testing Machine for Railroad Rails. Specimen has just fractured. The origin of the fatigue fracture can be seen near the upper right hand corner of the fracture section of the rail specimen.



be kept in mind that no one property can be used as the sole criterion of strength for all services. If the yield strength of a metal is lower than the endurance limit, then the latter frequently becomes of secondary importance. This is often the case for low-carbon steels under cycles of fluctuating but not reversing stress. For some steels at a temperature of about 1000 deg. F., or higher, resistance to creep under load becomes the governing factor.[1]

The endurance limit commonly determined is that under cycles of stress ranging from a maximum tensile stress to an equally great compressive stress. The effect of shearing stresses seems worthy of more attention than has been given to it in the past. This matter and the subject of fatigue strength under cycles of stress other than reversed stress are discussed in subsequent paragraphs.

Nomenclature and Definitions

Naturally with the growing use of the fatigue test in investigation, questions of nomenclature and definitions are arising. The American Society for Testing Materials Research committee has discussed this matter, and feels that up to the present time it is not wise to attempt any rigid standardization.[2] In this country it is usual to restrict the term "fatigue of metals" to that condition in which a progressive fracture has started, although the precise time when such a crack starts is not known. The terms "endurance limit" and "fatigue limit" are usually regarded as synonymous.

The question of nomenclature has usually centered about different ranges of stress during a cycle. In this country two systems are in rather common use:[2] (1) the ratio between the (numerical) minimum stress and the maximum stress is called the *range ratio.* This ratio is negative for wholly or partially reversed stress. The cycle is quantitatively defined by stating the range ratio (plus or minus), the maximum numerical stress, and for tension-compression stresses whether the maximum stress is tensile or compressive; (2) any cycle of stress is conceived as made up of a steady stress with an alternating stress superimposed. The cycle is quantitatively defined by stating the magnitude of the steady (mean) stress and the magnitude of range (or semi-range) of the alternating stress. The "direction" (tensile or compressive) of the mean stress must also be stated. This second system is commonly used in England. Various other systems of nomenclature have been proposed, but have not come into general use in this country.

Fatigue Testing Machines

Today in the United States probably 90 per cent of fatigue tests are made on rotating-beam testing machines—essentially the same type of testing machine as that used by Woehler some 75 yrs. ago. The commonest type of machine is one using a rotating specimen supported as a simple beam with two symmetrically placed loads (R. R. Moore). As the specimen revolves it is subjected to cycles of completely reversed flexural stress. The bending moment between loads is uniform, and the horizontal shear and the vertical shear are zero (note that there are shearing stresses on diagonal cross-sections). Cantilever machines are also in wide use. Rotating-beam machines either simple-beam or cantilever with speeds up to 10,000 or 12,000 r.p.m. are on the market.[3]

Vibratory fatigue machines have a considerable use, especially for testing thin sheet or thin strip metal.[3, 4] Usually the specimen serves as its own dynamometer. The stress-deflection diagram for the specimen is obtained by a static test. Usually the machine is so

designed that this calibration test can be made with the specimen in place in the machine. The throw of the crank or the strength of current in the alternating current magnet is then adjusted to give a deflection corresponding to the stress desired, and the test is run at that deflection. If the elastic properties of the specimen change during the test then the stress in the specimen changes. This sort of a test is known as a "constant-strain" test. The rotating-beam machine maintains a constant load, and a constant nominal stress during the test, and is known as a "constant-stress" test. The question of the difference in results produced by constant-stress machines and those by constant strain machines is a question demanding study at the present time.

Vibratory machines in which bending moment is measured by the deflection of an elastic spring, and is kept approximately constant by occasional adjustment during a test are available, and the range of flexural stress in a vibratory machine can be varied from complete reversal to one-direction stress.[3]

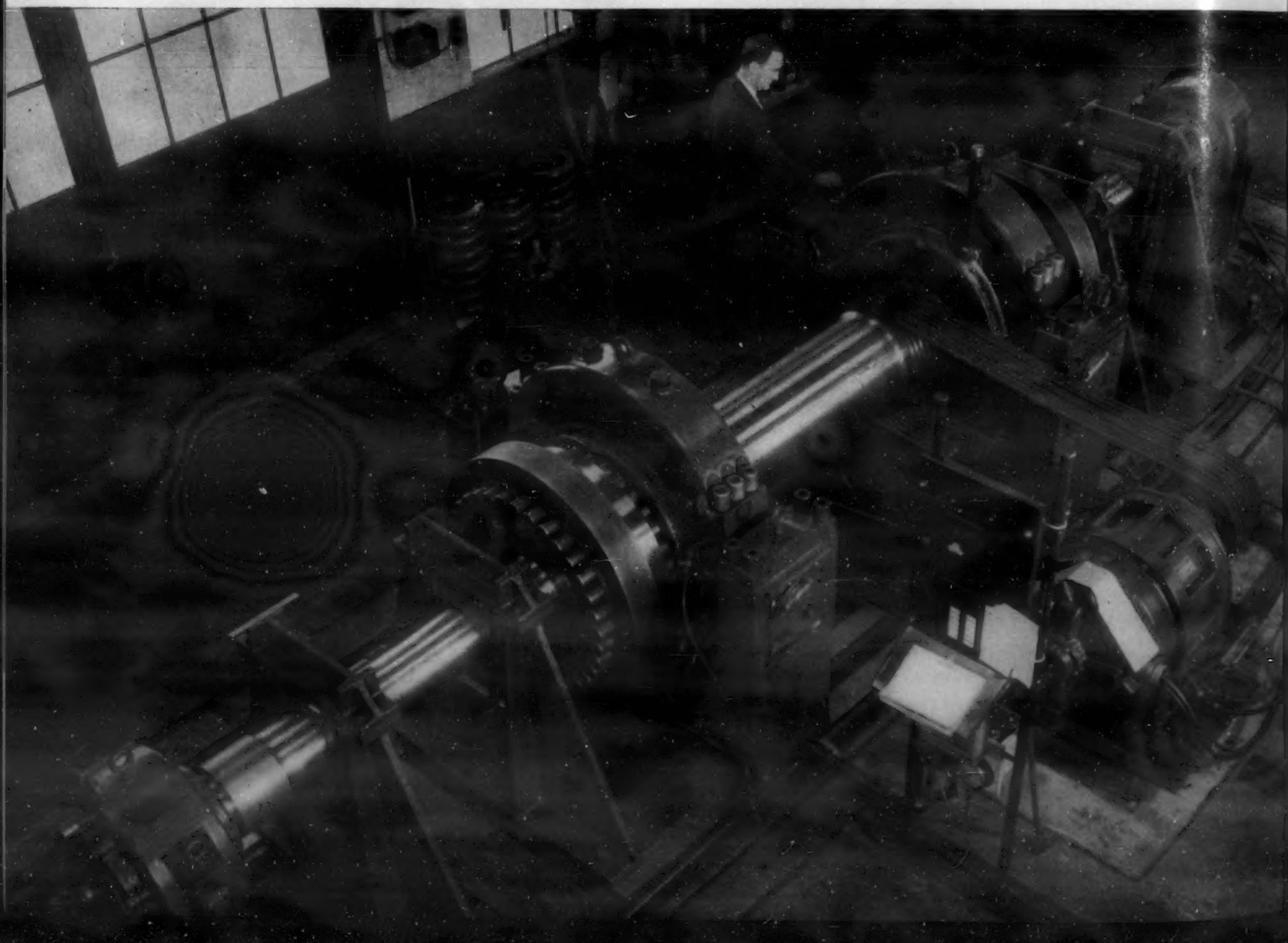
Fatigue testing machines for producing cycles of repeated axial stress (tension-compression) are especially useful when endurance limits under different ranges of stress are to be determined. If the maximum stress in a test cycle is beyond the yield strength of the metal, it is difficult to determine the magnitude of stress under flexure, but the stress can be determined with a satisfactory degree of accuracy in a test under axial stress (tension-compression). There is difference of opinion whether the endurance limit of a metal determined by reversed axial stress is the same as that determined by a rotating-beam (reversed flexure) machine. Probably if the yield strength of the metal is greater than the endurance limit, this is largely a matter of precise centering and even gripping of the specimen in the axial-stress machine.

Direct tension-compression machines are relatively expensive, and their use is rather rare. The principal machines in use in the United States are the electro magnetic machine (Haigh)[5] and the mechanically operated machine with an elastic ring or loop for measuring load (Moore-Krouse[3] and Templin[6]).

Torsion-fatigue machines have not come into wide use. This is to be regretted, as is the rather general lack of appreciation of the importance of shearing

A Locomotive Axle Testing Machine for Testing Full Size Locomotive Axles

(Courtesy: The Timken Roller Bearing Co.)



stress. The importance of shearing stress under torsion of shafts and axles is recognized, but the fact that, except under equal tensile or compressive stresses in three directions, there is always shearing stress present is not always appreciated. Moreover, the evidence today points toward the conclusion that fatigue cracks start under the influence of shearing stress, although once started, they tend to grow at right angles to the maximum tensile stress.

Torsion-fatigue machines in use are for the most part of one of two types. In the first type the torque necessary to oscillate a flywheel back and forth is transmitted through a test specimen, and the twisting moment and shearing stress are determined from the angular amplitude of oscillation, the frequency, and the moment of inertia of the flywheel (McAdam).[7] In the second type repeated or reversed torque is set up by a crank-connecting-rod mechanism, is transmitted through the test specimen, and the twisting moment and shearing stress is determined by the elastic twist of a steel weighbar. (Hankins, Moore).[3]

Large fatigue testing machines for testing full-size structural and machine parts are coming into increasing use. Large rotating-beam machines are in use for testing axles (Horger).[8] Some of the largest are capable of testing axles 13 in. in diameter with a speed of 2000 r.p.m. For testing full size specimens of wire rope at least one machine of the "Pulsator" type is in use. In this type of machine force is applied by a hydraulic cylinder with a specially designed pump, and the pressure applied is measured by some form of spring balance hydraulic indicator. Speeds up to 300 cycles of stress per minute have been used. Problems of avoiding "critical speeds" may have to be solved experimentally before using the pulsator type of machine on any given test specimen.

For setting up cycles of repeated stress in structures or machines a centrifugal force apparatus (Föppl, Bernard[9]) has received some attention in this country. A pair of unbalanced weights rotating in opposite directions with both weights reaching top and bottom positions simultaneously is placed in a containing box together with a driving motor. When the weights are at top position the resultant centrifugal force is upward and equal to the sum of that of the two weights; when at the bottom, a force of the same magnitude acts downward; when the weights are horizontal, their centrifugal forces neutralize each other. This apparatus has been used in studying fatigue strength of bridge trusses and of parts of ships.

Railroad rails are being tested by several experimenters by means of a "rolling-load" machine,[10] in which a full-section rail specimen is moved back and forth under a wheel loaded by means of a lever and a calibrated spring. Wheel load is varied by changing the compression of the spring and bending moment is varied by adjusting the supports under the rail specimen. Loads up to 80,000 lbs. have been used, with a speed of 60 cycles of stress per minute. The same machine may be used to measure wear or end-batter of rails.

A simple, effective machine, designed for fatigue tests of plate, riveted joints and welded joints consists of a single lever with the specimen hung from its "short" end. The lever is vibrated by a variable-throw crank, and the connecting rod between crank pin and the "long" end of the lever contains a calibrated elastic loop for measuring load (W. M. Wilson,[11] Templin). Knife edges are not used, but steel plate fulcra or narrow segments of steel cylinders with center of rotation at mid-depth of the lever are used. These machines are in use with capacities as high as 200,000 lbs. and a speed of 180 r.p.m. They can be used for tests under cycles of reversed axial stress (tension-compression), under cycles of one-way axial stress, and also for flexure tests.

Fatigue Test Specimens

For fatigue tests of full-size structural or machine parts obviously sample parts will be used for specimens. For tests of fatigue resistance of a metal specimens with reduced section at the section of maximum stress are commonly used. The reduction of section is made gradually so as to avoid sudden changes in cross-section which may act as "stress raisers." At the critical section and adjacent to it the surface of the metal is polished. For tests under tensile or compressive stress the final polishing is preferably in the direction of the stress, since scratches in that direction cause less stress concentration than those at right angles. For tests under shearing stress the direction of polishing is not so important, since the longitudinal shearing stress is equal in magnitude to the transverse. While the endurance limit determined from polished specimens is a valuable index of fatigue strength of the *metal,* it is frequently desirable to determine fatigue strength of a structural or machine part as modified by surface conditions, notches, fillets or holes, and stress history. The common rotating-beam specimen is suitable for studying the effects of notches, fillets, holes and stress history, but is not ordinarily suitable for studying surface conditions, since it is usually necessary to machine off the original surface at the reduced section. Axial-stress specimens (tension-compression) or vibratory-test specimens are better fitted for tests of effect of surface conditions.

Effect of Range of Stress During a Cycle

Experimental knowledge of fatigue strength under ranges of stress other than that of reversal from tensile stress to equally great compressive strength is meager.[12] It is quite probable that for different metals the ratio of endurance limits for different stress

ranges is not the same. Here is a field in which there is need for a large number of painstaking determinations of endurance limits for various stress ranges for many metals. For ratios of cycles of tensile-compressive stress, the axial-stress machine seems best fitted. An investigation of the possibilities of vibratory fatigue tests using I-shaped or hollow rectangular specimens would seem worth while. For effect of range of shearing stress the use of hollow torsion specimens with thin walls seems promising.

Effect of Combined Stresses

Combined stresses include tensile stresses, compressive stresses and combinations of the two acting in different directions, and combinations of tensile (or compressive) stress and shearing stress. Following the lead of Gough in England this problem is being taken up in at least one American laboratory. Do all metals react in the same way to various combinations of stress? Probably not, but we need many more test data. What data we have[13] at present suggests that, for ductile metals, fatigue strength is most closely correlated with *energy* of shearing stress or strain (VonMises-Hencky theory); for brittle metals the correlation is with either maximum stress or maximum strain (Rankine or St. Venant theory).

Effect of Speed of Testing and Size Effect

At various times experiments have been made on the effect of speed of testing on endurance limit. With the small specimens usually used it seems possible to run tests up to 5000 or 6000 cycles per min. on the approximate endurance limit.[3] Whether this holds true for larger specimens seems yet to be determined.

The question as to whether there is a "size effect" which causes lower endurance limits for large pieces than for small has received considerable attention (Peterson,[14] Moore and Jordan[15]). The results so far indicate that there may be such a size effect for ordinary fatigue specimens of some metals but there is very little, if any, size effect for others. However, when specimens with sharp notches, or sharp fillets are tested there seems to be a distinct size effect. This is further discussed in the next article.

(*To be concluded*)

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More About Nomenclature

To the Editor: Regarding the usefulness of Vilella and Cooper's proposed nomenclature for microconstituents in steel (METALS AND ALLOYS, September 1938, p. 223) when employed for classroom and laboratory instruction, I would like to say that our experience has been very similar to that of D. J. Mack (METALS AND ALLOYS, March, 1939, p. 101). However, I believe that explaining to the student what we mean is only half the problem, the other half being to teach him to understand whatever he may read about the subject in the literature.

The restriction of the use of the term sorbite to structures found in quenched and tempered steels seems to be in agreement with the ideas of most of our reformers in this field. But the ASM Metals Handbook recommends that if the term troostite is to be retained it should be reserved for "temper troostite." This is in direct contradiction to the recommendation of Vilella and Cooper that the term troostite "should not be used for any portion of the granular series."

It would, therefore, seem that some sort of compromise is essential if we are to avoid the introduction of additional confusion by our proposed reforms. I have found the compromise adopted by the metallurgists who recently revised Bullen's "Steel and Its Heat Treatment" (also reported in your editorial of June, 1938, p. A23) very satisfactory for both classroom and laboratory instruction. "Primary troostite" and "secondary troostite" still have much in common as far as microscopic appearance and physical properties are concerned, in spite of rather conclusive proof that they are not identical. From the standpoint of their utility it should be desirable to retain them in our nomenclature; but a further distinct advantage, possibly the greatest, in their preservation might be the fact that our future metallurgists would be able to understand the literature of their predecessors and of other countries, where the majority of authors do not appear to share our zeal in this reformation.

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